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OF THE

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INCLUDING THE

PROGRAMME OF THE

1958 ANNUAL MEETING

AT

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January 29–30–31 and February 1, 1958

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January 29, 1958 Series II, Vol. 3, No. 1

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1958 Annual Meeting at New York, January 29–February 1, 1958

THE **1958 Annual Meeting** of the American Physical Society will be held at New York on Wednesday, Thursday, Friday, and Saturday, **January 29, 30, 31, and February first,** 1958. The American Association of Physics Teachers (hereinafter to be denoted by AAPT) will share in the Ceremonial Session and in the banquet. The play will be wholly new, but the staging will depart in only two ways from that of last year. The headquarters hotel will be the New Yorker, as it has been for years, and most of the sessions will be held in its various halls. For the Ceremonial Session we have (we hope) successfully regained the great theater of the Manhattan Center, of which a misunderstanding (not our fault nor that of the American Institute of Physics) deprived us last year at the last minute. The North Ballroom will be used for an enlarged exhibit, and in exchange we have taken a hall in the Governor Clinton Hotel diagonally across Penn Station from the New Yorker. The Ceremonial Session will be held on Thursday afternoon; the banquet, in the Terrace Room of the New Yorker, is scheduled for seven on Friday evening.

From causes which we do not know but to which we are grateful, the number of ten-minute papers has not set a new record, but instead has declined by a very little from that of 1957. Nevertheless the visitors must look forward to crowded halls, crowded corridors, confusion on the registrants' though not on the registrars' side of the registration desk, and sessions longer in many cases than we should like to make them. The Local Committee is captained as last year by S. A. Korff and Arthur Beiser, but even they would find it hard to solve the problems of so great an assembly but for the precious and indispensable aid of the American Institute of Physics, many of whose staff will be engaged in our interest during the meeting days and some of whom have been prepared for it ever since September.

The **official hotel is the New Yorker,** which is at Eighth Avenue and 34th Street. This is opposite the northwest corner of Penn Station. Diagonally across Penn Station, opposite its southeast corner, is the Governor Clinton Hotel where we hold some of our sessions. Manhattan Center is next door to the New Yorker, westward on 34th Street. The Eighth Avenue subway stop is at the New Yorker, the Seventh Avenue subway stop is at the east side of Penn Station. In two previous issues of this Bulletin our members were admonished to get ahead of the rush by making their reservations right away. To facilitate the task of those who did not do so, we print on page 77 of this Bulletin a form which they are to fill out and mail.

The **registration desks** will be located in the North Ballroom Foyer on the mezzanine floor of the New Yorker (same place as one year ago!). Banquet tickets will be sold there. Post-deadline papers, if any, will be announced on a blackboard near the desk. There will be a special blackboard for notice of messages and of changes, should there be any, in the arrangements.

The **registration fee** will be **two dollars,** payable at the desk. These Annual Meetings are the costliest of all of ours, partly because of their size, partly because of expenses of various kinds which must be incurred when meetings are held in a hotel, partly because of the need of renting so capacious a theater as Manhattan Center for our grandiose annual event. Hitherto we have urged, with increasing vigor, the payment of the registration fee. Now we reach the stage of insistence. We hope we can rely on the honor system and not be obliged to proceed to the final step, which is that of posting hired guards to bar nonregistants from the sessions. Meanwhile we shall refuse to post any message handed in by anyone who has not registered and paid.

The **banquet** of the American Physical Society and of the AAPT will be held on Friday evening in the Terrace Room of the New Yorker. The 1958

Oliver E. Buckley Solid-State Physics Prize will be awarded. The after-dinner speakers will be James R. Killian, Jr., President of M.I.T. and Special Assistant to the President of the United States, and Elmer Hutchisson, new Director of the American Institute of Physics. This banquet being held on the third day of the meeting, we are not asking for advance reservations. You must, however, buy your tickets not later than 6 P.M. *Thursday* at the registration desk: the hotel sets places for only 5% more than the number of tickets sold by that time. Your tickets will be held for you if you pay in advance (by check made out to American Physical Society and mailed to Mr. E. P. Tober, 335 East 45th Street, New York 17, New York). The price will be $5.50.

The **Joint Ceremonial Session** of the two Societies will be held in Manhattan Center on Thursday afternoon, beginning at two o'clock. Our retiring President, H. D. Smyth, will deliver his address entitled "Past and present relations of science and government in the United States." The Oersted Medal of the AAPT will be conferred upon J. W. Buchta, who will respond with a speech named "A new era in science?" The sixteenth Richtmyer Memorial Lecture of the AAPT, entitled "The approximate nature of physical symmetries," will be given by Philip Morrison.

The **Oliver E. Buckley Solid-State Physics Prize** for 1958 will be awarded at the banquet to Nicolas Bloembergen.

Invited papers on the general programme are by H. H. Barschall, L. R. Bickford, Jr., Gregory Breit, S. C. Brown, G. F. Chew, S. A. Colgate, Martin Deutsch, J. F. Dillon, Jr., R. P. Feynman, E. H. Fitzgerald, Maurice Goldhaber, R. W. Hayward, Robert Hofstadter, V. Jaccarino, A. H. Kip, Franz Metzger, H. Palevsky, H. A. Pomerantz, B. Richter, J. Steinberger, P. H. Stelson, S. B. Treiman, J. L. Tuck, W. A. Wenzel, and Richard Wilson. Four of these (the discourses by Brown, Colgate, Kruskal, and Tuck) pertain to the phenomena of high-temperature plasmas. Also in the field of electron physics is a group of four papers invited by our Division of that name, the speakers being J. Kistemaker, J. Sayers, S. Borowitz, and B. Bederson. Our Division of Solid-State Physics takes credit for a group of invited papers by L. R. Bickford, Jr., J. F. Dillon, Jr., J. A. Ibers, W. C. Koehler, Lorenzo Sturkey, and M. K. Wilkinson, these pertaining to crystal structure revealed by diffraction of electrons and neurons.

Three hundred and sixty-seven contributed papers are disposed among thirty-two sessions. Last year's number was 376, the record for New York. Semiconductors have gained over last year, and so have beta and gamma emitters, perhaps because of the interest in parity, which is ramifying to such an extent that it is not always a simple matter to discern which papers bear on it and which do not—Session SA comprises some but probably not the whole of the former category. Nuclear magnetic resonance and neutrons are no longer of interest to nuclear physicists exclusively, and electron-spin resonance turns up in unexpected fields. Most welcome aid was extended by H. M. Foley who arranged the papers in theoretical physics, by C. H. Townes who accepted the corresponding task for magnetism and magnetic resonance, and by the Deputy Secretary who distributed the papers in neutron physics and nuclear reactions. This time, the biggest day for receipt of abstracts was the day before deadline: was this the effect of the admonition in the 1957 Washington Bulletin? One member (or maybe more than one?) will be disappointed to miss his abstract from this Bulletin, though it arrived in time: he forgot to put his name in.

The **Business Meeting** of the Society will be held at 4:45 P.M. on Wednesday in the Terrace Room of the New Yorker. The time though not the place was also last year's choice, and now that we have tried all hours of the day, without ever finding one which drew a crowd, we may make it the customary one. If the constitutional amendment now before the membership should have failed of adoption, there will probably be a run-off election at this meeting.

The **Council of the American Physical Society** will assemble on Tuesday, January 28, at 10:30 A.M., in the new building of the American Institute of Physics (335 East 45th Street) unless contrary notice is sent to its members.

The American Institute of Physics will conduct a **Placement Service Register** on the 5th and 6th floors of the New Yorker, January 29–February 1. The Register will be open until 9 P.M., Wednesday, Thursday, and Friday evenings and until noon on Saturday.

Post-deadline ten-minute papers pertaining to very recent achievements of very special importance will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society not later than Friday, January 24. The titles of such as are accepted will be displayed on a blackboard near the registration desk, and the papers will be given under the usual ten-minute rule at the end of

Session Z. The abstracts will not be published. Those who submit post-deadline papers will not be able to find out whether theirs have been accepted until the names appear on the blackboard. We expect nothing like last year's drama played before a suffocating house by the discoverers of nonconservation of parity, but who can tell? At any rate, we are no better prepared for such an event this year than we were last.

Preliminary announcements of the Chicago and Washington meetings appear on page 79 of this Bulletin. On page 80 are published the **calendar** of meetings and deadlines for the rest of the season and, below it, the rules and instructions for the preparation of abstracts. It will be very interesting to find out how many corrections to abstracts will have been received without the TEN DOLLARS which is their indispensable passport to the pages of this Bulletin. If none is received, we shall know that these instructions are read with the attention they deserve.

Errata pertaining to the contents of this issue will be published in a later issue of this Bulletin if received not later than Monday, February 3, by Miss Ruth Bryans, American Institute of Physics, 335 East 45th Street, New York 17, New York. Do not send in your abstract marked with corrections! Write out your corrections in the form "Instead of . . . read. . . ." Add nothing.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

EPITOME OF THE 1958 ANNUAL MEETING

(Personal names are those of invited speakers. All sessions are in the Hotel New Yorker excepting that in Manhattan Center and those in the Governor Clinton Hotel.)

Wednesday Morning

10:15	A.	Fission; neutron physics I. Terrace.
10:00	B.	Electron-spin resonance. Mosaic.
9:45	C.	Theoretical physics I: particles. Panel.
10:00	CA.	Pomerantz, Fitzgerald, Dillon, Bickford. Boston.
9:45	D.	Semiconductors I. Governor Clinton.
10:00	DA.	Stelson, Metzger, Hayward, Wilson. Grand.

Wednesday Afternoon

2:00	E.	Semiconductors II. Governor Clinton.
2:00	EA.	Cryogenics; Palevsky. Boston.
2:00	F.	Barschall; neutron physics II. Panel.
2:15	G.	Division of Solid-State Physics: Ibers, Sturkey, Koehler, Wilkinson. Terrace.
2:00	GA.	Theoretical physics II (particles); Chew, Breit. Grand.

Wednesday Afternoon at 4:45

4:45		Business Meeting of American Physical Society. Terrace.

Thursday Morning

9:45	H.	Nuclear moments; nuclear resonances. Boston.
9:45	HA.	Strange particles. Terrace.
9:45	J.	Nuclear reactions I. Panel.
9:45	JA.	High-temperature plasma; Tuck, Colgate, Kruskal, Brown. Grand.
9:45	K.	Spectroscopy. Empire.
9:45	KA.	Semiconductors III; radiation damage. Governor Clinton.

Thursday Afternoon

2:00	L.	Joint ceremonial session: Smyth, Buchta, Morrison. Manhattan Center.

Friday Morning

9:15	M.	Pions and muons; Steinberger. Terrace.
9:45	MA.	Theoretical physics III: various topics. Empire.
9:30	N.	Nuclear reactions II. Panel.
9:30	NA.	Division of Electron Physics: Kistemaker, Sayers, Borowitz, Bederson; Business Meeting. Grand.
9:45	P.	General physics. Boston.
9:15	PA.	Ferro-, ferri-, antiferro-magnetism. Governor Clinton.

Friday Afternoon

2:00	Q.	Ferroelectricity, magnetism; Jaccarino, Kip. Governor Clinton.
2:45	QA.	Hofstadter, Richter. Panel.
2:00	R.	Electron physics. Terrace.
2:00	S.	Theoretical physics IV: nuclear structure. Boston.
2:00	SA.	Form factors; proton scattering; polarization and parity; recoil experiments. Grand.

Friday Evening

7:00		Banquet of APS and AAPT; Killian, Hutchisson. Terrace.

Saturday Morning

9:45	T.	Theoretical physics V: atomic structure, statistical mechanics. Empire.
9:45	TA.	Feynman, Deutsch, Goldhaber, Wenzel. Grand.
9:45	U.	Nuclear reactions III. Boston.
9:45	UA.	Apparatus of nuclear physics. Terrace.
9:45	V.	General solid-state physics. Governor Clinton.
9:45	VA.	Beta and gamma emitters I. Panel.

Saturday Afternoon

1:45	W.	Beta and gamma emitters II. Panel.
1:45	X.	Fluid dynamics. Governor Clinton.
1:45	XA.	Theoretical physics VI: relativity, collision processes. Empire.
1:45	Y.	Metals. Boston.
1:45	Z.	Cosmic rays; post-deadline papers, if any. Grand.

PROGRAMME

WEDNESDAY MORNING AT 10:15

Terrace Room

(V. L. SAILOR presiding)

Fission: Neutron Physics, I

A1. Anisotropy of α-Particle Emission from Oriented U^{233} Nuclei. G. W. PARKER, L. D. ROBERTS, AND J. W. T. DABBS, *Oak Ridge National Laboratory.*—Studies similar to those previously reported[1,2] for U^{233} and Np^{237} α-particle emission have now been extended to U^{235} and U^{234}. The method involves aligning a distorted nucleus by means of the crystalline electric field gradient in a $UO_2Rb(NO_3)_3$ single crystal at low temperatures and observing the α-particle emission in various directions. In the case of U^{234}, a spin zero, even-even nucleus, no alignment is expected; hence, the α-particle emission should be isotropic and independent of temperature. This was found to be correct. On the other hand, the amount of alignment of U^{235} nuclei should be similar to that previously found for U^{233}. An anisotropy of comparable magnitude was observed, leading to an expression for the angular distribution given by

$$W(\theta) = 1 - (0.068 \pm 0.01) P_2(\cos\theta)/T.$$

This may be compared with the coefficient of $P_2(\cos\theta)$ for U^{233} which was found to be $-0.0625/T$.

[1] Roberts, Dabbs, Parker, and Ellison, Bull. Am. Phys. Soc. Ser. II, 1, 207 (1956); Dabbs, Roberts, and Parker, *ibid.* Ser. II, 1, 207 (1956).
[2] Dabbs, Roberts, and Parker, Bull. Am. Phys. Soc. Ser. II, 2, 31 (1957).

A2. Anisotropy of Fission Fragments from Oriented U^{233} Nuclei. L. D. ROBERTS, J. W. T. DABBS, AND G. W. PARKER, *Oak Ridge National Laboratory.*—Experiments carried out simultaneously on the fission fragment anisotropy and α-particle anisotropy from a system of aligned U^{233} nuclei showed an α-particle anisotropy, as previously reported, but revealed a much smaller anisotropy (by a factor of about 5) in the fission fragment angular distribution. The fission events were induced by thermal neutron capture. In this experiment, the presence of the α-particle anisotropy served to demonstrate that the nuclei were indeed aligned, and the magnitude of this anisotropy served as a "thermometer." The small size of the fission fragment anisotropy may reveal features of the fission process with the help of simplified models (see following abstract).

A3. Fission of Oriented Nuclei and the Bohr Model. J. W. T. DABBS, L. D. ROBERTS, AND G. W. PARKER, *Oak Ridge National Laboratory.*—At present, the only model available for accounting for the angular distribution of fission fragments from oriented nuclei is the one proposed by Bohr.[1] We have put Bohr's suggestion into a mathematical formulation and can compare the results with the experiments (see preceding abstract). In the Bohr picture, under the assumption of a single channel for the fission of U^{233}, there is only one way in which an isotropic distribution of the fragments can arise from an oriented nuclear spin system. Since this is essentially the experimental result, it is possible to assign angular momentum values to this single fission channel. A comparison of the Bohr picture with angular momentum theory shows them to give the same results in certain very simple situations.

[1] A. Bohr, *Proceedings of the International Conference on the Peaceful Uses of Atomic Energy (Geneva, Switzerland)* (United Nations, New York, 1956), Vol. 2, p. 151.

A4. Bromine Delayed Neutron Precursor of 1.4-sec Half-Life.* G. J. PERLOW AND A. F. STEHNEY, *Argonne National Laboratory.*—We have improved our technique for rapid isolation of halogen fission products,[1,2] and have found a neutron activity with a half-life of 1.4±0.6 sec in the bromine fraction. The fissionable material was irradiated with neutrons for measured times as short as 0.52 sec, and counting of the chemically separated bromine activities commenced at about 2 sec after the end of irradiation. The bromine was swept out of an irradiated solution by means of a fast-moving stream of air and was absorbed in a thin film of CCl_4 adhering to glass beads packed in a column. BF_3 counters were used in a suitable arrangement for counting fast neutrons emanating from the column. In order to display the new activity it was necessary to subtract the contributions from 54-sec Br^{87}, 15.5-sec Br^{88}, and 4.2±0.5 sec Br^{89}. For the shortest irradiation the 1.4-sec activity contributed 40% of the counting rate at the start of the counting period, while the 4-sec activity contributed 50%. On the basis of an observed regularity in the half-lives of the bromine delayed neutron precursors, we tentatively assign the new period to Br^{90}, hitherto unobserved.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] G. J. Perlow and A. F. Stehney, Phys. Rev. 107, 776 (1957).
[2] G. J. Perlow and A. F. Stehney, Bull. Am. Phys. Soc. Ser. II, 2, 309 (1957).

A5. Neutron Energy Dependent Mass Distribution in U^{233} Fission.* R. B. REGIER, W. H. BURGUS, J. R. SMITH, AND M. S. MOORE, *Phillips Petroleum Company.*—Application of the collective model to neutron induced fission[1] leads to the prediction that the mass distribution of fission fragments depends upon the spin state of the resonance responsible for the fission. Theoretical analysis[2] of the U^{233} fission cross section indicates that the first two strong resonances in U^{233}, at 1.8 and 2.3 ev, belong to a different spin state from that involved in the large majority of thermal fissions. To test the prediction, the ratio of the thermal fission yield of Mo^{99} to Ag^{111} was compared with the ratio obtained from fission with 1.8-ev neutrons provided by the MTR crystal spectrometer. Using saturated activities as a measure of fission yields, it was found that the activity ratio of Mo^{99}/Ag^{111} at 1.8 ev was larger by 15±3% than the ratio obtained at thermal energies. This is in apparent disagreement with the result of Roeland *et al.*[3] Work with other fission products and other resonance energies is in progress.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. A. Wheeler, Physica 22, 1103 (1956).
[2] Moore, Miller, and Reich, Bull. Am. Phys. Soc. Ser. II, 1, 327 (1956).
[3] Roeland, Bollinger, and Thomas, Bull. Am. Phys. Soc. Ser. II, 2, 352 (1957).

A6. Isotropy of Gamma Rays Emitted during Nuclear Fission. MARVIN HOFFMAN, *Los Alamos Scientific Laboratory.**—Gamma-rays from thermal neutron fission of U^{235} have been measured at three angles to the direction of the fission fragments. The fragments were collimated into a cone with a half-angle of 22°. The fission fragments passing through the collimator were recorded by a gas scintillation counter. The intensity of gamma rays in several energy intervals above 300 kev was measured at angles of 180°, 135°, and 90° from

the direction defined by the collimator. The gamma-ray pulses from a NaI(Tl) crystal photomultiplier combination placed 70 cm from the fission foil were recorded by a pulse-height analyzer. The output of a fast-slow coincidence system gated the pulse-height analyzer when a coincidence occurred between a gamma ray and a fission fragment. The flight time of fission neutrons over the 70-cm path was sufficient to eliminate neutron-fission fragment coincidences. The accidental coincidence rate was about 15% of that between gamma rays and fission fragments. The ratio of all observed gamma rays at the three angles was $I_{180}/I_{135}=1.025\pm0.043$ and $I_{180}/I_{90}=1.025\pm0.043$. Similar measurements using U^{235} and Pu^{239} nuclides will also be reported.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

A7. Thermal Neutron Flux in a Medium with a Temperature Discontinuity. D. A. KOTTWITZ, *Hanford Atomic Products Operation.*—The energy and spatial dependence of the steady-state neutron flux has been derived for a nonabsorbing infinite medium consisting of a heavy monatomic gas, the temperature of which has a constant value in one half-space and a different constant value in the other. The heavy gas and P_1 approximations lead to a partial differential equation which is separable for each region. Each resulting energy eigenfunction is the product of the Maxwellian flux function and a Laguerre polynomial of order one. Evaluation of the series expansion coefficients is difficult if both flux and current are required to be continuous at the boundary plane. However, if the flux and gradient are joined continuously, allowing a slight mismatch in current, the coefficients are readily obtained for all temperature cases. Numerical results of this calculation will be presented. An interesting general conclusion, which comes directly from integration of the partial differential equation, is that the asymptotic values of integrated (over energy) flux for large distances from the discontinuity are the same for both regions. This is a characteristic of a Knudsen gas and is consistent with the Onsager theorem concerning coupled irreversible processes.

A8. Energy Distribution of Neutrons Slowing Down in a Gas of Point-Particles.* NOEL CORNGOLD, *Brookhaven National Laboratory.*—Solutions to the neutron thermalization problem have been given for a gas composed of point particles with mass equal to the neutron mass,[1] and with mass very large compared with the neutron mass.[2] This paper shows that, if one uses the asymptotic expansion of scattering cross section suggested by Placzek[3] and Wick,[4] one can extract from the Boltzmann equation for neutron density a series solution in terms of the variable $(\xi T/E)$. No restriction on the moderator mass is necessary. The paper also discusses the circle of convergence of the series, its connection with the special solutions mentioned previously, and extension of the analysis by analytic continuation.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] E. P. Wigner and J. E. Wilkins, Jr., AECD-2275 (1948).
[2] For references see E. R. Cohen, Nuclear Sci. and Eng. **2**, 227 (1957).
[3] G. Placzek, Phys. Rev. **86**, 377 (1952).
[4] G. C. Wick, Phys. Rev. **94**, 1228 (1954).

A9. Dynamic Properties of Neutron Amplifiers. BERNARD BROWN, *New York University.*—The dynamic properties of neutron amplifiers[1-3] may be analyzed from the viewpoint of general amplifier characteristics. The gain of a neutron amplifier is described for the case where neutrons are fed back to earlier stages of the amplifier. A neutron amplifier is proposed in which the neutron feedback is controlled by limiting the neutron transfer between stages. The properties of a fast neutron amplifier are analyzed, including the effect of transients on amplifier stability. The application of a neutron amplifier to power production is discussed. The lower multiplication factor of the neutron amplifier relative to a critical reactor is shown to increase the breeding ratio and decrease the fuel inventory requirements per stage.

[1] L. B. Borst, Bull. Am. Phys. Soc. Ser. II, **2**, 224 (1957).
[2] P. Michael and L. B. Borst, Bull. Am. Phys. Soc. Ser. II, **2**, 225 (1957).
[3] L. B. Borst, Phys. Rev. **107**, 905 (1957).

A10. Convergatron Amplifier Characteristics. L. B. BORST AND P. MICHAEL, *New York University.*—A polar neutron amplifier must be operated near the critical condition to achieve an output greater than the input to a stage. Since the only neutron sink in the system is the thermal neutron barrier, expedients can be used to reduce the flow to this region. The moderator zone must restrict the backward flow of epithermal neutrons to avoid excessive feedback, yet permit the forward flow of thermal neutrons to the subsequent stage. The choice of moderator and the variation of moderator and fuel distribution will be discussed in the light of these requirements.

WEDNESDAY MORNING AT 10:00

Mosaic Room

(A. F. KIP presiding)

Electron-Spin Resonance

B1. Magnetic Moment of Helium in Its $^3S_1$ Metastable State.* C. DRAKE, A. LURIO, V. W. HUGHES, AND J. A. WHITE, *Yale University.*—The ratio of the electronic g_J value of He in its $1s\,2s$, $^3S_1$ metastable state to the g_J of H in its ground state has been redetermined by the atomic beam magnetic resonance method using separated oscillatory fields. At magnetic fields of about 540 and 580 gauss the transitions $\Delta M=\pm1$, ±2 in He and $(F,M)=(1,0)\leftrightarrow(1,-1)$ in H are observed at frequencies of approximately 1570 Mc/sec and 1140 Mc/sec, respectively. The natural line shapes for the separated oscillatory fields method are obtained with spacings between the oscillatory fields of both 4.5 cm and 2.2 cm. The experimental result is

$$g_J(\mathrm{He},{}^3S_1)/g_J(\mathrm{H},{}^2S_{\frac{1}{2}})\text{expt.}=1-(23.3\pm0.8)\times10^{-6},$$

which agrees with an earlier measurement[1] having an accuracy of 16 ppm, and also with the theoretical value[2]

$$g_J(\mathrm{He},{}^3S_1)/g_J(\mathrm{H},{}^2S_{\frac{1}{2}})\text{theoret}=1-(23.2\pm1.0)\times10^{-6},$$

computed from the Breit equation for He with the addition of a term to represent the interaction of the anomalous spin magnetic moment of each electron with the external magnetic field.

* This research has been supported in part by the National Science Foundation and by the U. S. Air Force Office of Scientific Research.
[1] Hughes, Tucker, Rhoderick, and Weinreich, Phys. Rev. **91**, 828 (1953).
[2] W. Perl and V. W. Hughes, Phys. Rev. **91**, 842 (1953).

B2. Atomic g_J Values for Neon and Argon in the Metastable $^3P_2$ State.* A. LURIO, C. DRAKE, V. W. HUGHES, AND J. A. WHITE, *Yale University.*—The ratios of the electronic g_J values of Ne and A in their metastable $^3P_2$ state to the g_J of He in its metastable $^3S_1$ state have been redetermined[1] by the atomic beam magnetic resonance method using separated oscillatory fields. At a magnetic field of 550 gauss transitions between Zeeman levels of Ne or A and of He are observed at frequencies of approximately 1157 Mc/sec and 1543 Mc/sec. If the known value $g_J(\mathrm{He})=2[1.0011183-(8)]^2$ is used, the results obtained are $g_J(\mathrm{Ne},^3P_2)_{\mathrm{expt}}=1.50088-8(5)$ and $g_J(\mathrm{A},^3P_2)_{\mathrm{expt}}=1.500964(8)$. Relativistic corrections[3] to the Lande g_J value of 1.5 for a $^3P_2$ state have been computed using Slater wave functions. If these corrections are combined with the spin g_s value for the electron of $g_s=2(1.0011596)$,[4] the following theoretical values are obtained: $g_J(\mathrm{Ne},^3P_2)_{\mathrm{theoret}}=1.50088$ and $g_J(\mathrm{A},^3P_2)_{\mathrm{theoret}}=1.50106$. The agreement of the experimental and theoretical g_J values for Ne is excellent; the discrepancy for A may be due to the effects of configuration interaction which are not included in the theoretical value.

* This research has been supported in part by the U. S. Air Force Office of Scientific Research.
[1] Drake, Hughes, and Lurio, Bull. Am. Phys. Soc. Ser. II, 2, 37 (1957).
[2] See preceding abstract.
[3] W. Perl, Phys. Rev. 91, 852 (1953); A. Abragam and J. H. Van Vleck, Phys. Rev. 92, 1448 (1953).
[4] C. Sommerfield, Phys. Rev. 107, 328 (1957).

B3. Microwave Zeeman Spectrum of Atomic Oxygen.* H. E. RADFORD AND V. W. HUGHES, *Sloane Physics Laboratory, Yale University.*—The technique of paramagnetic resonance absorption has been used to measure the g values of the ground ^3P states of O^{16} in terms of the proton g value. The results are $-g_J\ (\mathrm{O};^3P_1)/g_P=493.4236\pm0.0002$ and $-g_J\ (\mathrm{O};^3P_2)/g_P=493.4022\pm0.0002$ where g_P refers to protons in a cylindrical sample of mineral oil. These agree with earlier, less precise measurements by Rawson and Beringer.[1] When combined with $g_J\ (\mathrm{H};^2S_{\frac{1}{2}})/g_P$, measured in analogous experiments on hydrogen, and after inserting the theoretical value of $g_J\ (\mathrm{H};^2S_{\frac{1}{2}})$, the results are $g_J\ (\mathrm{O};^3P_1)=1.500986\pm0.000002$ and $g_J\ (\mathrm{O};^3P_2)=1.500921\pm0.000002$. These are smaller by 7 ppm than the corresponding theoretical g values,[2] computed with $g_s=2(1.0011596)$.[3] Alternatively, theory and experiment can be reconciled by taking $g_s/g_L=2(1.001179)$. Considering this as a measurement of g_s/g_L, the limits of error are determined entirely by uncertainties in the theoretical oxygen g values.

* This work was supported in part by the Office of Naval Research.
[1] E. B. Rawson and R. Beringer, Phys. Rev. 88, 677 (1952).
[2] See following abstract by F. R. Innes.
[3] C. M. Sommerfield, Phys. Rev. 107, 328 (1957).

B4. Zeeman Effect Calculations in Atomic Oxygen. F. R. INNES, *Air Force Cambridge Research Center.*—Computed g values of the ground term of atomic oxygen are found to be 1.500931 and 1.500995 for levels $^3P_2$ and $^3P_1$, respectively,[1] very slightly larger than corresponding values based upon observation.[2] In this instance the computation of relativistic and diamagnetic effects[3] was made on the basis of the ground configuration alone. In other cases, superposition of configurations should introduce small changes, but here the admixture of configurations is slight and the resulting changes negligible. It is possible to conclude (following Kambe and Van Vleck[4]) that the given values are accurate, subject to the use of separable wave functions of the Hartree-Fock type. Investigation of g values pertaining to other atomic species is indicated, preferably for levels in which departure from Russell-Saunders coupling and admixture of configurations remain small.

[1] K. Kambe and J. H. Van Vleck, Phys. Rev. 96, 66 (1954); F. R. Innes and C. W. Ufford, Phys. Rev. (to be published).
[2] H. E. Radford and V. W. Hughes (preceding paper).
[3] The interaction is given by W. Perl, Phys. Rev. 91, 852 (1953); A. Abragam and J. H. Van Vleck, Phys. Rev. 92, 1448 (1953).
[4] Reference 1, Sec. IV.

B5. Gyromagnetic Ratio of Sb^{123}. F. M. PIPKIN, *Harvard University.*—The hyperfine splitting of 60-hr Sb^{122} donors in a doped silicon crystal has been measured by using the orientation produced by the application of various radio-frequency fields to detect the resonances. The orientation signals are similar to those obtained for As^{76}.[1] For Sb^{122} the relaxation time for processes in which the electron and nucleus flip their spins simultaneously so that $\Delta(m_I+m_J)=0$ is shorter than for As^{76} and orientation can be produced by the Overhauser effect. To make a precise determination of the hyperfine splitting, a double saturation experiment was performed. The microwave rf field was set so as to saturate the central $(\frac{1}{2},0)\rightarrow(-\frac{1}{2},0)$ transition; the low-frequency rf was then swept over the region of the $(-\frac{1}{2},m_J)\rightarrow(-\frac{1}{2},m_J+1)$ transitions. From these measurements it is concluded that, for S^{122}, $A=-132.6\pm0.4$ mc/sec. The known gyromagnetic ratio of Sb^{121} and Sb^{122},[2] together with the hyperfine splitting for their donor atoms in a silicon crystal,[3] can be used to calculate the gyromagnetic ratio of Sb^{123}. The value $g=-0.952\pm0.004$ is obtained.

[1] F. M. Pipkin and J. W. Culvahouse, Phys. Rev. 106, 1102 (1957).
[2] W. G. Proctor and F. C. Yu, Phys. Rev. 81, 20 (1951).
[3] G. Feher (private communication).

B6. Electron Spin Resonance of Ultraviolet Irradiated Organic Compounds.* CHARLES P. POOLE AND ROY S. ANDERSON, *University of Maryland.*—The 9000 Mc electron spin resonance spectra of over 100 ultraviolet irradiated organic compounds maintained at 77°K have been recorded at a g factor of two. The mechanism of radical production entails the absorption of the photon by a pi electron and the subsequent rupture of a nearby bond. Unsaturated hydrocarbons show well-resolved, symmetric, evenly spaced hyperfine structure of three to six lines. Aldehydes are characterized by a strong singlet attributed to the formyl radical on which there is superposed weaker time decaying multicomponent structure attributed to alkyl radicals. Nitrogen-containing compounds exhibit triplet structure resulting from the nuclear spin of nitrogen. Other classes of compounds will be discussed, including ketones, esters, acids, anhydrides, and halides. In general the resonances obtained are characteristic of the class of compound irradiated, and in many cases the radicals may be identified by the spacing and intensity ratios of the hyperfine structure components. Line widths and component separations are about two milliwebers per square meter. Line widths calculated from dipole-dipole interaction with surrounding protons agree with the observed widths. While most radicals are stable for weeks at 77°K, some change or decay with time indicating secondary reactions.

* This research was supported by the U. S. Air Force under contract monitored by the Air Force Office of Scientific Research of the Air Research and Development Command.

B7. Computation of the Principal Components of an Asymmetric (g) Tensor From Paramagnetic Resonance Data.* J. E. GEUSIC AND L. CARLTON BROWN, *Ohio State University.*—In the case of a paramagnetic crystal in which the effective Hamiltonian of the paramagnetic ion is

$$H=\sum_{ij}\beta g_{ij}H_iS_j$$

a method will be outlined by which one can obtain in a simple and direct manner the components of the $(g_{ij})^2$ tensor from rotation data about any three mutually orthogonal axes whose relation to the crystal axes is known. Finally from the components of the $(g_{ij})^2$ tensor the principal g components and the orientation of the principal coordinate system of this g tensor relative to the arbitrary orthogonal system are found.

* This work was supported in part by a contract between the Office of Scientific Research of the Air Research and Development Command, Maryland, and The Ohio State University Research Foundation.

B8. Electron Spin Resonance Line Shapes for Solids Having Nonisotropic g Factors.* ROGER P. KOHIN AND CHARLES P. POOLE, JR., *University of Maryland.*—The line shape for a paramagnetic substance having three unequal

g tensor components $g_1>g_2>g_3$ and a spin of $\frac{1}{2}$ is derived assuming that the molecules have a random distribution of orientations. If the component line shape for a particular orientation is assumed to have zero width, the line shape, normalized to unit area, is[1]

$$I(g)=\begin{cases}2gK(b/a)/\pi a & g_3\leq g\leq g_2\\ 2gK(a/b)/\pi b & g_2\leq g\leq g_1\\ 0 & \text{otherwise,}\end{cases}$$

where

$$a=[(g_2^2-g_3^2)(g_1-g^2)]^{\frac{1}{2}}$$
$$b=[(g_1^2-g_3^2)(g^2-g_3^2)]^{\frac{1}{2}}$$

and K (k) is a complete elliptic integral of the first kind. This line shape is characterized by an infinite peak at $g=g_3$ and shoulders at $g=g_1$ and g_2. Integrations performed over nonzero component line widths are discussed.

* This research was supported by the U. S. Air Force under contract monitored by the AFOSR of the Air Research and Development Command.

[1] A similar line shape has been previously discussed with reference to nuclear magnetic resonance in metals by Bloembergen and Rawland, Acta Met. 1, 731 (1953).

B9. Paramagnetic Resonance Line Width Studies of $(Zn,Ni)SiF_6\cdot 6H_2O$.* R. H. Hoskins, R. C. Pastor, and K. R. Trigger, *Hughes Aircraft Company*.—This investigation, at 9 kmc, was undertaken to determine the mechanisms responsible for the widths of the paramagnetic resonance lines of $(Zn,Ni)SiF_6\cdot 6H_2O$. The parameters, g and δ, and the relaxation times are in agreement with those obtained by previous workers.[1] At liquid helium temperatures the widths were approximately 20% less than those at 77°K. At given temperature, the widths were approximately constant in the concentration range of Zn/Ni of 10^2 to 10^5. From the observation that the widths were independent of crystal orientation, it was concluded that the widths did not arise from a distribution in the value of δ, as might result from nonuniformities within the crystal. Crystals of $(Zn,Ni)SiF_6\cdot 6D_2O$ yielded different values of g and δ but, however, widths within a few percent of the hydrated samples. $(Ni\cdot 6H_2O)^{2+}$ in other host-lattices has been investigated. The significance of these results will be discussed.

* This work was supported in part by the U. S. Signal Corps.

[1] Penrose and Stevens, Proc. Phys. Soc. (London) **A63**, 29 (1950); Holden, Kittel, and Yager, Phys. Rev. **75**, 1443 (1949); J. W. Meyer, Lincoln Laboratory, 1955 (unpublished).

B10. Measurement of Spin-Spin Relaxation Time in Phosphorus-Doped Silicon.* A. Honig and E. Stupp, *Syracuse University*.—The electronic spin-lattice relaxation times are of the order of minutes for sufficiently dilute concentrations of phosphorus in silicon. Because of this isolation of the spin system from the lattice, it has been possible to investigate directly the kinetics of the spin-spin relaxation by a simple procedure. Abragam and Combrisson have shown that a partial spin temperature is established at a value of the magnetic field such that the Zeeman and hyperfine energies are equal. At this field value, a redistribution of the populations of the three lowest lying states can occur via the spin-spin interaction without any energy exchange with the lattice. By sweeping the magnetic field through this region at varying rates, and subsequently measuring the populations of the different hyperfine levels by microwave resonances, we obtained a measure of the spin-spin relaxation time. For a phosphorus concentration of $1.4\times 10^{16}/cm^3$, about 1 second must be spent in passing over the line width to obtain half of the relaxation. In interpreting this result, it must be kept in mind that for a particular value of the external magnetic field, the spin packets that can interact to produce a spin temperature are restricted to those which do not require energy from the lattice.

* Supported by the U. S. Air Force Office of Scientific Research of the Air Research and Development Command.

B11. Solid-State Masers and Spin-Lattice Relaxation Times.* C. F. Davis, M. W. P. Strandberg, and R. L. Kyhl, *MIT*.—Interpretation of the operational properties of a solid-state maser, which we have operating in our Laboratory, indicate that the process conventionally described as spin-lattice relaxation indeed plays a dominant role in the operation of these devices. As has been pointed out,[1,2] the spin-relaxation process must be extended to include phonon relaxation processes which in fact can dominate, in the sense that anomalous phonon temperatures can exist in the vicinity of the saturation frequency.

* This work was supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research).

[1] Strandberg, Davis, and Kyhl, "Measurement of spin lattice relaxation times with pulse techniques," Fifth International Conference on Low Temperature Physics and Chemistry, Madison, Wisconsin, August 30, 1957.
[2] van den Marel, van den Broek, and Gorter, Physica **23**, 361 (1957).

B12. Paramagnetic Relaxation at Very Low Temperatures.* F. R. Nash, J. A. Giordmaine, L. E. Alsop, and C. H. Townes, *Columbia University*.—A series of experiments using paramagnetic resonance at microwave frequencies and in the 1–2°K temperature range on $Gd_2Mg_3(NO_3)_{12}\cdot 24H_2O$, $K_3Cr(CN)_6$, and $Cu(NH_4)_2(SO_4)_2\cdot 6H_2O$ indicate the following characteristics for the relaxation of these substances. It is the lattice-bath relaxation which limits the total rate of relaxation. The spin-lattice relaxation time is several orders of magnitude smaller than the normally observed values of T_1. The breadth of the lattice modes is very much larger than the width of the resonances in diluted crystals, and in particular for 1% paramagnetic concentrations of $Cu(NH_4)_2(SO_4)_2\cdot 6H_2O$, the breadth is several hundreds of megacycles. The breadth of the lattice modes increases with increasing concentration of paramagnetic centers. In a time comparable with the spin-lattice relaxation time two nearby resonances are brought to the same effective temperature by exchange of energy through the broadened lattice modes which connect the spins. The observed relaxation time T_1 is dependent upon crystal size. Characteristics imply a number of other properties connected with paramagnetic relaxation, and the importance of heat conduction by diffusion of phonons.

* Work supported jointly by the Signal Corps, the Office of Naval Research, and the U. S. Air Force Office of Scientific Research.

B13. Preservation of Spin State in Free Atom-Inert Surface Collisions.* H. G. Robinson, E. S. Ensberg, and H. G. Dehmelt, *University of Washington*.—Employing an optical technique similar to the one described earlier[1] spin relaxation measurements were carried out on rubidium vapor at about 10^{-7}mm contained in a 200-cc spherical bulb whose walls were coated with eicosane, $C_{20}H_{42}$, a straight chain saturated paraffin. Experimental "decay times" as long as 57×10^{-3} sec for the weakest light intensity used were observed which lead to a relaxation time of 165×10^{-6} sec. This implies that at least 600 atom-wall collisions occur before appreciable disorientation of the spins sets in or the atoms are lost. Continuous evacuation insured a residual pressure of less than 10^{-4} mm as measured with a Langmuir vibrating vane gauge mounted inside the cell. The rubidium atoms evaporated from a short uncoated side arm held at the same temperature as the whole cell, namely 38°C, and disappeared through the pump lead and possibly by chemical reactions with the paraffin. Noticeable shortening of the relaxation time with increased temperature lends some support to the latter assumption. Strong paramagnetic resonance signals were observed in the earth's field with the transmission monitoring technique. Results of further paramagnetic resonance experiments using coated cells and successive oscillatory fields will be reported.

* Sponsored by the Office of Ordnance Research, U. S. Army.

[1] H. G. Dehmelt, Phys. Rev. **105**, 1487 (1957).

WEDNESDAY MORNING AT 9:45

Panel Room

(J. D. JACKSON presiding)

Theoretical Physics I: Particles

C1. Velocity Dependence of the Two-Nucleon Interaction.* R. E. MARSHAK AND S. OKUBO, *University of Rochester.*—It has been shown[1] that the addition of the term linear in the nucleon momentum (spin-orbit potential) to the static two-nucleon interaction leads to a good fit of all existing scattering data up to 150 Mev. The fit at 300 Mev is less satisfactory and the question arises whether the further addition of terms quadratic in the nucleon momentum would improve the fit at the higher energies. As the first step we have studied the most general form of the nonrelativistic two-nucleon interaction containing quadratic (and higher) powers of the nucleon momentum. We find that if one stays on the energy shell[2] the only essentially new term in the potential is of the form $(\sigma_1\cdot L)(L_2\cdot L)$. We next seek guidance from meson theory as to the structure of this quadratic spin-orbit potential. We find that this quadratic spin-orbit term arises as a correction of order $(\mu/M)^2$ (μ is the pion mass and M is the nucleon mass) to the second-order static potential.

* Supported in part by the U. S. Atomic Energy Commission.
[1] P. S. Signell and R. E. Marshak, Phys. Rev. 106, 832 (1957).
[2] Cf. Puzikov, Ryndin, and Smorodinsky, Joint Institute preprint.

C2. On Generalized Gauge Transformations.* F. GÜRSEY, *Brookhaven National Laboratory.*—Attention is drawn to a 4-dimensional symmetry of the pseudoscalar meson-nucleon system. This is best studied by analyzing the nucleon wave function (p,n) into two 4-spinors ψ and ζ defined by $\psi=\frac{1}{2}(1-\gamma_5)p+\frac{1}{2}i(1+\gamma_5)p^c$ and $\zeta=\frac{1}{2}(1-\gamma_5)p-\frac{1}{2}i(1+\gamma_5)p^c$. It is shown that when χ and ζ undergo Paulis' generalized gauge transformations $\chi\sim a\chi+b\gamma_5\chi^c$ and $\zeta\sim a'\zeta+b'\gamma_5\zeta^c$, $(|a|^2+|b|^2=|a'|^2+b'|^2=1$, we obtain a 4-dimensional rotation group which leaves the quadratic form $m^2+g^2\pi^2$ invariant (m is the nucleon mass and π denotes the meson field). Isotopic spin rotations correspond to $a'=a$, $b'=b$ while transformations of the Dyson-Foldy type follow from the special case $a'=a^*$, $b'=-b$. Under such transformations p and n are mixed, but not χ and ζ. However parity (I') and charge conjugation (C) mix χ and ζ. Parity conserving terms in the Lagrangian contain χ and ζ in a symmetrical manner while interaction terms involving only χ (or ζ) destroy both C and P invariance. Such weak interactions may be introduced by the B field technique of Yang and Mills in the specialc ase $a'=1$, $b'=0$, a and b being arbitrary functions of space-time variables.

* Work performed under the auspices of the U. S. Atomic Energy Commission and the International Cooperation Administration.

C3. Mass Reversal and Weak Interactions.* J. J. SAKURAI,† *Cornell University.*—An attempt is made to construct a theory of all weak processes from a single invariance principle. The requirement that the weak interaction Hamiltonian be invariant under the reversal of the sign of the mass in the Dirac equation separately for *any* fermion leads to a unique form of the four-fermion interaction responsible for weak processes. The Hamiltonian contains equal amounts of V and A, and is necessarily invariant under time reversal but noninvariant under parity regardless of whether or not the neutrino field is involved. (Our results are identical to those obtained by Feynman and Gell-Mann and by Sudarshan and Marshak using somewhat different approaches.) The possible existence of an intermediate *charged* boson field responsible for all weak processes is discussed with reference to several weak processes which have not been observed. Most experiments in β decay and the π-μ-e sequence are consistent with the predictions of our theory with the important exception of the He[6] recoil experiment. Various implications of our theory which can be experimentally tested are examined with special attention to the decay interactions of hyperons and K mesons. In particular a large asymmetry in the Λ decay is predicted.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Cornell University Senior Graduate Fellow.

C4. Application of the Heitler-London Method to the Two-Nucleon Problem. R. E. CUTKOSKY, *Carnegie Institute of Technology.*—The two-nucleon system is being studied by a method which is based on explicit construction of the eigenstates, using a representation which depends on the exact one-nucleon eigenstates. A fixed source model of the meson-nucleon interaction is being used in the preliminary study. The Heitler-London representation is defined by operators, which, when operating on the vacuum, create physical one-nucleon states, with given numbers of incident mesons. (Specification of the dependence of these operators upon the canonical variables selects unique operators.) Heitler-London states, defined by products of these operators, are exact two-nucleon eigenstates for large separations. Automatically renormalized expansions for the energy, average number of mesons, charge density, etc., are easily derived. The interaction energy given by the familiar linear fixed source theory is being calculated by this method. The two-meson exchange part of the energy agrees with the result of Miyazawa,[1] but with more exchanged mesons, some numerically small but interesting new terms appear, which do not have the usual type of exponential decay.

[1] H. Miyazawa, Phys. Rev. 104, 1741 (1956).

C5. Clothed Particle Operators in Simple Models of Quantum Field Theories. O. W. GREENBERG,* *Air Force Cambridge Research Center,* AND S. S. SCHWEBER, *Brandeis University.*—The idea of using clothed operators, that is operators which create and annihilate one-particle eigenstates of the total Hamiltonian, in field theory is examined. The operators presently used in field theory, such as the renormalized Heisenberg operator, do not have this property. These clothed operators are related to the unrenormalized Schrödinger picture operators by canonical transformation. Using the clothed operators, the usual renormalization of mass and charge is extended to the renormalization of the states and operators appearing in the theory. The virtual cloud of particles surrounding a physical particle in present discussions of field theory is no longer present corresponding to the elimination of persistent effects from the theory.[1] Mass and wave function renormalization are automatically accomplished by the clothing transformation. The form of the Hamiltonian expressed in terms of clothed operators is discussed. These ideas are applied to the static scalar model, the Lee model, and the van Hove-Ruijgrok model.

* At Brandeis University during most of this work.
[1] L. van Hove, Physica 21, 901 (1955) and 22, 343 (1956).

C6. Mass Effect in *P*-State π-*P* Scattering.* H. Y. CHIU, *Cornell University.*—In a recent phase analysis[1] it is found

that $(\delta_{13}-\delta_{11})$ is of the order of 7° at 150 Mev and is spectacularly large (~20°) at 220 Mev. A suggestion has been made to explain this discrepancy as due to the difference in masses of charged and neutral pions. On assuming a definite mesonic charge "g" in analogy to the electrodynamic case, one finds a different f, the pseudovector coupling constant in Chew-Low theory, through the formula,

$$f_{\pm,0}=\left(\frac{\mu_{\pi^\pm,\pi^0}}{2M}\right)g,$$

and then the Kemmer's interaction Hamiltonian becomes

$$H_I=f\sum_i\bar{\psi}\tau_i\phi_i\psi+af\bar{\psi}\tau_3\phi_3\psi,$$

where $a=(\mu_{\pi^0}-\mu_{\pi^\pm})/\mu_{\pi^\pm}\approx-0.03$. Near resonance this perturbation term $af\bar{\psi}\tau_3\phi_3\psi$ may be coupled to the large resonance amplitude and gives additional terms to the well-known scattering formula:

$$(\pi^+P\to\pi^-P)=\tfrac{1}{3}[a(\tfrac{1}{2})+2a(\tfrac{1}{2})]$$

$$(\pi^-P\to\pi^0n)=\frac{\sqrt{2}}{3}[a(\tfrac{1}{2})-a(\tfrac{1}{2})].$$

An investigation at both high and low extreme energies is made.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] H. Y. Chiu and E. L. Lomon, "Pion nucleon phase shifts for intermediate energies" (to be published in Phys. Rev.).

C7. Comparison of Σ^+p and Σ^-n Systems.* GEORGE A. SNOW, *U. S. Naval Research Laboratory*.—The assumption of charge symmetry for the interaction between Σ hyperons and nucleons implies that the forces in the Σ^+p and the Σ^-n systems differ only by the repulsive Coulomb force in the former (we neglect the Σ^+, Σ^- mass difference). Let us assume that the Σ^-n system is bound with a binding energy ϵ_-, and inquire as to the binding energy ϵ_+ of the Σ^+p system. In particular we wish to determine the maximum value, $\bar{\epsilon}_-$, such that the Σ^+p system has zero binding energy. Taking a square well potential for the Σ^-n system of range b, we find that the condition $\epsilon_+\to0$ implies that $\bar{\epsilon}_-=0.38$, 0.47, 0.62 Mev for $b=1.4$, 1.0, 0.6×10^{-13} cm, respectively. Hence one sees that there is a non-negligible energy region, $0<\epsilon_-<\bar{\epsilon}_-$, such that Σ^-n is bound and Σ^+p is unbound. Conversely if Σ^+p is bound[1] Σ^-n has a binding energy greater than the values of $\bar{\epsilon}_-$ given in the foregoing. For the special case $\epsilon_+=0.014$ Mev, the Schrödinger equation for the Σ^+p system has a particularly simple solution which illustrates clearly the effect of the Coulomb field on the wave function.

* Supported in part by the U. S. Atomic Energy Commission.

[1] Baldo-Ceolin, Fry, Greening, Huzita, and Limentani, Nuovo cimento **6**, 144 (1957).

C8. Some Remarks on the TCP Theorem.* T. KINOSHITA AND M. ZAIDI, *Cornell University*.—The TCP theorem is usually proved under the assumption of (1) invariance under proper Lorentz transformation, (2) local field theory, (3) Hermiticity of Hamiltonian, (4) usual connection between spin and statistics (which requires the antisymmetrization of fermion fields), and (5) anticommutativity of kinematically independent fermion fields. Of these, the last one may only be a simplifying assumption and may not be essential to the theorem. In view of this, an attempt is made to see how general field theories behave under strong reflection when one omits the assumption (5). For this purpose, use is made of (a) consistency of the Lagrangian formalism of relativistic field theories and (b) microscopic causality (or integrability). When applied to given interaction Hamiltonians, these assumptions compel us to assume anticommutativity between *some* of the fermion fields. Of course, (5) is not equivalent to (a) and (b) in general. In an important case where all fermions can be classified into only *two families* (family is defined by the property that fermions in a given family must anticommute with each other while those belonging to different families are not subject to any definite commutation relation), the TCP theorem holds without help of assumption (5). More complicated cases will also be discussed.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

C9. Photoproduction of Pion Pairs.* RONALD F. PEIERLS, *Cornell University*.—A general expression for the angular distribution of pion pairs photoproduced from nucleons is derived from phenomenological considerations. It is expressed in terms of the S-matrix elements for production in definite angular momentum and isotopic spin states. Under various assumptions about the nature of the interaction, such as the absence of a meson-meson interaction, the distribution is obtained for the case when one s-state and one p-state pion are produced (assuming the latter to interact only in the 33 state). It is expressed in terms of two arbitrary amplitudes and the scattering phase shifts. This is then compared with the predictions of the Chew-Low theory[1] under the same assumptions. Possible experiments to test some of these assumptions are discussed.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] R. E. Cutkowsky and F. Zachariasen, Phys. Rev. **103**, 1108 (1956).

C10. Charge-Dependent Corrections to Pion-Nucleon Scattering.* D. M. GREENBERGER, *MIT*.—If account is taken of the mass difference between neutral and charged pions and of the possibility that the three coupling constants (π^0-p, π^0-n, $\pi^\pm$-nucleon) may differ, then the pion-nucleon system no longer conserves isotopic spin. This effect has been investigated using Chew-Low theory with a p-state interaction. For each J value there are ten scattering amplitudes, replacing the two of the charge independent case. Only eight of these amplitudes are independent due to time reversal invariance. They are determined as solutions to a set of linear integral equations which may be solved exactly in the one-meson approximation, neglecting crossing terms and, approximately, including them. The cross sections for pion scattering are then written in the form $(A+\Delta A)+(B+\Delta B)\cos\theta+(C+\Delta C)\cos^2\theta$, where A, B, C represent the "charge-independent" part of the scattering. The corrections go through a maximum at about 120 Mev. The coupling constant corrections can contribute as strongly as those due to the mass difference. Numerical results will be presented.

* Work supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission, and the University of Illinois.

C11. Photoproduction of K-Mesons and the K-Meson Parity.* B. T. FELD AND G. COSTA, *MIT*.—We consider the associated production of a hyperon and a K meson by photons on protons. The angular distributions and energy dependences of the cross sections yield information from which it may be possible to infer the relative parity of the produced Y-K with respect to the nucleon parity. General, qualitative considerations are given, based only on the assumption that the photoproduction reaction features are determined by the nature of the Yukawa interaction, nucleon$\rightleftarrows Y+K$, from which the parity may be inferred. In particular, it is shown in terms of a simple model of the Yukawa interaction that the relatively unambiguous interpretation of photoproduction requires the observation of processes involving hyperons and K-mesons in different charge states, e.g., $\gamma+P\to\Lambda+K^+$, Σ^0+K^+, $\Sigma^+ + K^0$. The possible importance of enhancement

of the reactions in special states is considered and its possible effects on the interpretation of photoproduction observations will be discussed.

* Work supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

C12. The $\gamma\pi^3$ Vertex in Photopion Processes. CHARLES J. GOEBEL, *University of Rochester.*—An interaction which may contribute to high-energy photopion processes is the $\gamma\pi^3$ vertex (generated by a closed nucleon loop). To illustrate its character, consider the primitive process: photoproduction of π^0 by γ incident on a $\pi^\pm$; the cross section goes as (c.m. energy)^4 for $\mu <$ c.m. energy $< M$. In lowest order, using $G^2/4\pi = 15$, we find for a photon with lab energy M a cross section of 25 μb. The maximum differential cross section occurs at *ca* 20°, but one cannot expect to see this forward peaking in $\gamma N \to \pi^2 N$ because the rapidly rising cross section favors interaction with a virtual pion which is moving backwards in c.m. Further, final state interaction will likely obscure the process. The use of polarized bremsstrahlung would be of interest, since in $\gamma N \to \pi^2 N$ by the $\gamma\pi^3$ vertex, the *nucleon* recoil would show the azimuthal asymmetry only weakly. The contribution of the $\gamma\pi^3$ vertex to $\gamma N \to \pi N$ will be discussed.

C13. Photomeson Production from Hydrogen and Deuterium.* JACK L. URETSKY, *University of California, Berkeley.*—The ratios of cross sections for the two processes $\gamma + d \to \pi^+ + 2n$, $\gamma + p \to \pi^+ + n$ were computed by use of the dispersion-relation theory of Chew *et al.*[1] The final state of the two-neutron system was first taken to be a plane wave,[2] and then the corrections resulting from ^1S scattering were added. At low meson energies and small angles the ^1S scattering contributes about 15% to the deuteron cross section. Satisfactory agreement with the recent experiments by Knapp[3] is obtained by using ^1S scattering parameters $a_s = -17 \times 10^{-13}$ cm and $r_{0s} = 2.6 \times 10^{-13}$ cm.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Chew, Goldberger, Law, and Nambu, Phys. Rev. 106, 1345 (1957).
[2] M. Lax and H. Feshbuch, Phys. Rev. 88, 509 (1952).
[3] Knapp, Kenney, Perez-Mendez, and Perkins, Bull. Am. Phys. Soc. Ser. II, 2, 320 (1957).

C14. Time-Reversal Invariance for Two-Pion Decay of θ^0 Meson. S. OKUBO, *University of Rochester.*—If the time-reversal or charge conjugation invariance does not hold for the two-pion decay modes of the θ^0 meson, then generally the θ_2^0 meson, as well as θ_1^0, may decay into two-pions, thus making it difficult to explain the long lifetime of θ_2^0. The sufficient conditions to forbid this were studied under the assumption that we may neglect the mass shifts of the θ^0 meson. Besides charge-conjugation or time-reversal invariance, another sufficient condition is when we have the selection rule $\Delta I = \pm\frac{1}{2}$ for the isotopic spin. Other possible conditions are accidental cancellations. Since the rule $\Delta I = \pm\frac{1}{2}$ appears to give the wrong branching ratio for $\pi^+ + \pi^-$ and $2\pi^0$ decay, it seems that charge conjugation or time-reversal invariance holds to a good approximation in this decay, if we ignore the possibility of accidental cancellations.

WEDNESDAY MORNING AT 10:00

Boston-Washington Room

(W. F. G. SWANN presiding)

Invited Papers in Solid-State Physics

CA1. Conductivity Induced in Nonconducting Crystals by High-Energy Electron Bombardment. H. A. POMERANTZ, *Bartol Research Foundation.* (30 min.)

CA2. Mechanical Dispersion in Metals and Crystalline Polymers at Audio-Frequencies. E. H. FITZGERALD, *Pennsylvania State University.* (30 min.)

CA3. Domain Structure and Optical Properties of Transparent Ferrimagnetic Crystals. J. F. DILLON, JR., *Bell Telephone Laboratories.* (30 min.)

CA4. Magnetic Annealing in Cobalt-Iron Ferrites. L. R. BICKFORD, JR., *IBM Research Center, Poughkeepsie.* (30 min.)

WEDNESDAY MORNING AT 9:45

Governor Clinton

(R. N. HALL presiding)

Semiconductors I

D1. Investigation of Capacitance of Forward Biased Junctions. T. E. FIRLE AND O. E. HAYES, *Hughes Aircraft Company.*—The susceptance of a forward biased junction at low currents was derived theoretically by Shockley.[1] In most devices at normal operating forward biases the diffusion component is predominant. In view of newer devices with nonlinear impurity concentrations, an investigation of the junction admittances becomes again of interest. Recently Evans[2] has reported experimental data on fused alloy germanium emitter capacitance taken on transistors. The "capacitance" (for the equivalent parallel circuit model) increases to a maximum as a function of current, decreases through zero and becomes inductive, finally reaching an inductive plateau. We have made impedance measurements on silicon alloy junctions of various sizes and history and on silicon diffused transistors. For low currents capacitance varies directly with current. Increasing the current beyond fractions of a milliampere, however, leads to a maximum at about 1–2 ma. Then the capacitance decreases to zero at 2–4 ma (typically twice the value for the maximum). No inductive saturation could be positively established even for currents as high as 500 ma. In addition to complete impedance data we present the observed dependence of forward impedance on frequency.

[1] W. Shockley, Bell System Tech. J. 28, 335–489 (1949).
[2] D. M. Evans, J. Electronics 1, 468 (1956).

D2. Temperature Dependence of Noise in Transistor Structures. C. A. LEE AND G. KAMINSKY, *Bell Telephone*

Laboratories.—A study of the temperature dependence of the noise in transistor structures has been made. The principal interest has been the behavior of the noise above the usual $1/f$ spectrum. The noise occurring in this portion of the spectrum is believed to be caused by fundamental mechanisms affecting the diffusion and transport of charge carriers in the body of the semiconductor rather than surface mechanisms to which the $1/f$ spectrum is generally attributed. Both germanium and silicon transistors constructed with the use of diffusion and alloying techniques have been studied. The room temperature results in germanium transistors show excellent agreement with theories proposed by Van der Ziel[1] and by Guggenbuehl and Strutt,[2] as have the experimental results of several investigators. However, the variation of the noise with temperature in germanium and silicon shows a marked deviation with the theories already mentioned. It is suggested that another mechanism affecting the diffusion and transport of carriers other than those considered by Van der Ziel (lifetime and diffusion) is responsible for the different temperature dependence.

[1] A. Van der Ziel, Proc. Inst. Radio Engrs. **43**, 1639 (1955).
[2] W. Guggenbuehl and J. O. Strutt, Proc. Inst. Radio Engrs. **45**, 839 (1957).

D3. Conductivity Change of a Chemisorbing Semiconductor. H. A. BROWN, *National Carbon Research Laboratories.*—The change in the conductivity parallel to the surface of a semiconductor has been calculated as a function of the density of chemisorbed gas ions on the surface. The conductivity change is roughly proportional to the change in carrier density and a better approximation is obtained by including the decrease in the mean free time, τ for carriers near the surface. A simple kinetic theory argument is used to derive the dependence of the mean free time on depth. The solution of the electrostatic problem by Schottky's approach[1] gives the carrier density as a function of depth, $n(x)$, and the conductivity is proportional to the integral of $n(x)\tau(x)$. Finally, the integral of $n(x)$ can be related to the surface density of adsorbed ions, or to the surface potential if desired. The calculation has been performed for a cumulative and a depletive case and for a semi-infinite adsorber as well as a thin film.

[1] W. Schottky and E. Spenke, Wiss. Veröffentl. Siemens-Werken **18**, 1 (1939).

D4. Argon Bombarded Germanium Surfaces. SUMNER P. WOLSKY, *Raytheon Manufacturing Company* (introduced by W. T. Eriksen).—A quartz microbalance with which weight differences of 0.1μg can be detected has been set up in an ultra-high vacuum system. Pressures of 2×10^{-10} mm of Hg are attainable. The behavior of germanium surfaces cleaned by argon-ion bombardment has been studied. In addition to the usual bombardment method, samples have also been prepared by bombardment at 475°C. The room temperature kinetics of oxidation of the clean germanium surfaces have been observed at oxygen pressures of 3 mm and 10^{-4} mm. It has not been possible to pump off any of the oxygen adsorbed in the kinetic runs. Bombarded samples were exposed to vacua of 10^{-8} to 10^{-9} mm for varying periods of time. Subsequent heating of these samples to 475°C generally caused no appreciable weight loss.

D5. Inversion Layer Transient Measurements Giving Evidence of Finite Mobility of Charges in Outer Surface States. H. STATZ AND G. A. DEMARS, *Raytheon Manufacturing Company.*—Transient measurements of inversion layer conductance clearly show that the positive charges in outer surface states can move under some circumstances when electric fields exist parallel to the surface. This movement is observed only when thick adsorbed films are present which result from the vapors of certain liquids. All measurements were made on n-p-n silicon bars in ambients containing acetone vapor. The electric fields parallel to the surface result from the saturation current which is collected by the inversion layer and which flows via the inversion layer to the n-regions. The inversion layer conductivity changes when voltage pulses are applied to the base region and the charge in the outer surface states redistributes itself. The observed changes in the conductivity of the inversion layer give information about the mobility of the charge. A thorough discussion will be given of the effects which are observed when the applied voltage pulses are high enough for pinchoff to occur. As it also will be shown, the finite mobility gives rise to possible instabilities of inversion layers. Contrary to previous belief, the mobility of the charge in the outer surface states is low enough so that no direct contributions to the conductance of the inversion layer but only the induced changes in the inversion layer conductance are observable.

D6. New Surface Current Multiplication Process. G. A. DEMARS AND H. STATZ, *Raytheon Manufacturing Company.*—The described measurements were carried out on n-p-n silicon bars in ambients containing acetone vapor which, in general, produced inversion layers on the p region. If certain conditions relating to the mobility of the charge in the outer surface states, the relaxation time, the magnitude of the saturation current, and the equilibrium charge density exist the surface charge redistributes itself on the surface in such a manner that sharp potential drops occur where the inversion layer meets the main p-n junctions. The potential of the inversion layer with respect to the p region may be only a small fraction of the applied voltage. It is found that the saturation current which is collected by the inversion layer is multiplied while flowing through the steep potential drop in the vicinity of the main junctions. The field strengths involved are too small for conventional avalanche multiplication. It is proposed that the "electron temperature" is high enough to ionize interface states and thus to provide a current multiplication. To check this hypothesis multiplication measurements were made as a function of oxidation which is known to increase the number of interface states. The experimental results will be reported and consequences of the findings will be discussed.

D7. Distribution of Electrons in Nonpolar Semiconductors at Intermediate Electric Fields. I. ADAWI, *RCA Laboratories.*—The velocity distribution of electrons in a semiconductor is investigated using the gaseous discharge analogy which Shockley[1] has previously used. The collision term in the Boltzmann equation is expanded as a power series in the energy transfer. This simplification leads directly to the Davydov[2] distribution. The mobility, random velocity and energy are calculated and their behavior is discussed for electric field strengths E such that $0\leq eEL/k,\leq 1$ which approximately defines the intermediate range.

[1] W. Shockley, Bell System Tech. J. **30**, 990 (1951).
[2] See Chapman and Cowling, *Mathematical Theory of Non-uniform Gases* (Cambridge University Press, New York, 1953), second edition, p. 346.

D8. Field-Induced Changes in the Electron Distribution Function for Germanium in the Presence of Acoustical and Optical Mode Scattering.* THOMAS N. MORGAN,† *University of Illinois.*—When an electric field is applied to a semiconducting sample, the distribution in energy of the electrons is displaced toward higher energies. The amount of this displacement depends upon the efficiency of the scattering processes in delivering to the lattice the energy supplied by the field and may be determined from the solution of the Boltzmann equation. Such a solution has been obtained with the aid of the University of Illinois digital computer for the case of small fields in germanium with scattering by both acoustical and optical vibrational modes present. The change produced in the distribution function by the field is found to show a periodic behavior with a period equal to the characteristic energy of the optical phonons. The corresponding mobility

change induced by the field has been calculated for this function and for a Maxwellian-type function corresponding to an effective electron temperature greater than the lattice temperature. These results provide a reasonable interpretation of the experimental values obtained with relatively pure samples between 80 and 300°K.

* Research supported by the Office of Ordnance Research, U. S. Army.
† Now at the I. B. M. Watson Laboratory.

D9. Drift Mobility of Electrons and Holes in Germanium at Pressures to 30 000 kg/cm².* ARTHUR C. SMITH, *Harvard University.*—The effect of hydrostatic pressures up to 30 000 kg/cm² on the drift mobilities of electrons and holes in germanium has been determined. Drift mobility was measured by the Haynes-Shockley technique as modified by Lawrance and Gibson. The drift mobility of electrons decreases as pressure is applied; the value at 30 000 kg/cm² is about one-fourth of the atmospheric pressure value. The pressure dependence of the mobility agrees within experimental error with the pressure dependence of the conductivity of extrinsic *n*-type samples, indicating that a change in carrier density does not occur. The drift mobility of holes increases linearly with pressure at a rate of about 1% per 10 000 kg/cm² for temperatures between 195°K and 296°K. This rate of increase agrees with that deduced from conductivity measurements. Assuming scattering due to lattice vibrations only, and using data on the change of elastic constants with pressure, it is found that an increase in the effective mass of the high mass holes of 2% in 10 000 kg/cm² is necessary to fit the data. The change in the effective mass with pressure of the low mass holes of about 16% in 10 000 kg/cm², deduced from the motion of the (000) conduction band minimum, does not affect the average mobility appreciably.

* Supported in part by the Office of Naval Research, under contract with Harvard University.

D10. Pressure and Temperature Dependence of the Effective Mass of Electrons in Germanium.* MARSHALL I. NATHAN,† WILLIAM PAUL, AND HARVEY BROOKS, *Harvard University.*—Measurements of the pressure dependence of the electrical resistivity of *n*-type germanium at several temperatures where lattice scattering is predominant can be interpreted largely in terms of interband scattering between (111) and (100) minima. However, there remains an explicit dependence of the effective mass, $(1/m^*)^2=\frac{1}{3}(1/m_1m_2^2)\frac{1}{3}[(1/m_1)+(2/m_2)]$, on volume, to which an upper limit can be set. The demonstration of a small explicit temperature dependence of the effective mass allows us to deduce the total temperature dependence of m^*. Our results show that $|dm^*/m^*dp|\leq 8\cdot 10^{-12}$/dyne cm^{-2} and $|dm^*/m^*dT|\leq 1.2\times 10^{-4}$/°C. The maximum additional temperature dependence of the electron mobility resulting from intravalley acoustic mode scattering is $T^{-0.04}$ much smaller than is required to explain the $T^{-0.16}$ present discrepancy between the simple theory and experiment. It is shown that the effective mass cannot change by more than 4% between 4°K and 300°K. If the large temperature dependence of the average effective mass deduced by other workers from experiments is genuine, it must be the result, not of changes in band curvature, but of deviations from parabolic character of the bands.

* Supported by the Office of Naval Research.
† Union Carbide Fellow.

D11. Investigation of Minority Carrier Recombination in Irradiated Germanium.* O. L. CURTIS, JR., AND J. W. CLELAND, *Oak Ridge National Laboratory.*—Measurements of minority carrier lifetime as a function of irradiation have been extended to intrinsic and *p*-type germanium. In addition, lifetime measurements have been made as a function of temperature on both *n*-type and *p*-type germanium which has been irradiated. Carrier lifetime was determined from the decay of conductivity following injection by a light pulse. The effect of both neutron and gamma-ray irradiations on material with a range of initial carrier concentrations was examined. Electron lifetime in *p*-type germanium is quite sensitive to irradiation, the sensitivity being comparable to that of hole lifetime in *n*-type material. For recombination centers introduced by Co^{60} gamma rays, the electron capture cross section appears to be lower than for those introduced by neutrons. The recombination probability increases at a rate which is somewhat less than linear with irradiation.

* This work was supported by the U. S. Atomic Energy Commission.

D12. Grain Boundary Conduction in Germanium Bicrystals. H. F. MATARÉ, B. REED, AND O. WEINREICH, *Sylvania Electric Products.*—Conductivity measurements on grain boundary layers obtained by controlled growth of bicrystals with two (100) seeds tilted about a (100) axis were carried out in the temperature range between 300°K and 4°K. The characteristics of these *p*-type interfaces in bicrystals grown from antimony-doped (*n*-type) melts were discussed earlier.[1] Anomaly in their behavior with respect to minority carrier flow was found[2] and photoelectrical effects were described.[3] The low resistivity path of these boundaries was found here without the use of gold doping.[4] While deionization of impurity levels increases the resistivity of the monocrystalline sides by the usual factor of 10^3 to 10^6 from 300° to 4°K, the grain boundary layer maintains an almost constant value of 0.05 ohm cm over this temperature range, with a linear I-V characteristic. Assuming a uniform width of the conduction region (~100A), the conductivities of the interfaces in *n*- and *p*-type material (doped with gallium) differ by less than a factor of 10. Copper diffusion does not change this behavior. Field effect measurements show interface-current modulation.

[1] H. F. Mataré, Phys. Rev. **98**, 1179 (1955); Z. Naturforsch. **10a**, 640 (1955); Z. Physik **145**, 206 (1956); **148**, 631 (1957). Tayler, Odell, and Fan, Phys. Rev. **88**, 867 (1952).
[2] H. F. Mataré and B. Reed, Z. Naturforsch. **11a**, 876 (1956).
[3] Weinreich, Mataré, and Reed, Bull. Electrochem. Soc. Washington, May 12–16, Abstract 58 (1957).
[4] A. G. Tweet, Phys. Rev. **99**, 1182 (1952).

WEDNESDAY MORNING AT 10:00

Grand Ballroom

(C. S. WU presiding)

Invited Papers in Nuclear Physics

DA1. Level Positions and Transition Rates from Coulomb Excitation. P. H. STELSON, *Oak Ridge National Laboratory.* (30 min.)

DA2. Lifetimes of Nuclear States As Determined by Resonance Fluorescence Experiments. FRANZ METZGER, *Bartol Research Foundation.* (30 min.)

DA3. Beta-Gamma Angular-Correlation Experiments with Polarized Nuclei. R. W. HAYWARD, *National Bureau of Standards.* (30 min.)

DA4. Scattering of Polarized Protons. RICHARD WILSON, *Harvard University.* (30 min.)

WEDNESDAY AFTERNOON AT 2:00

Governor Clinton

(C. G. B. GARRETT presiding)

Semiconductors II

E1. Piezoresistance Effect in Tellurium. DONALD LONG AND ROBERT PU, *Honeywell Research Center.*—The piezoresistance effect has been observed in single crystals of tellurium grown by the Czochralski method.[1] Preliminary measurements have been made at several temperatures between 77°K and 350°K of the change of resistivity parallel to the c axis caused by a tensile stress applied parallel to the c axis. The resistivity decreases at all temperatures, but the magnitude of the decrease is much larger in the intrinsic range than at 77°K. The fractional decrease of resistivity is roughly 6×10^{-11} per dyne/cm^2 at 77°K and 35×10^{-11} per dyne/cm^2 at 350°K. Because of the anomalous compressibility of tellurium,[2] this type of piezoresistance measurement is analogous to an experiment in which one measures the effect of a hydrostatic pressure on the resistivity of tellurium, and the results can be qualitatively explained in the same way as the pressure results.[3] Similar experiments to those reported here have been done by A. Sagar.[4]

[1] T. J. Davies, J. Appl. Phys. **28**, 1217 (1957).
[2] P. W. Bridgman, Proc. Am. Acad. Arts Sci. **60**, 305 (1925).
[3] J. Bardeen, Phys. Rev. **75**, 1777 (1949); D. Long, Phys. Rev. **101**, 1256 (1956); J. R. Reitz, Phys. Rev. **105**, 1233 (1957).
[4] A. Sagar (private communication).

E2. Electrical Properties of Mercury Telluride.* T. C. HARMAN AND M. J. LOGAN.—Mercury telluride has been prepared from pure elements by direct reaction of mercury vapor with liquid tellurium. The electrical properties of HgTe were varied over a considerable range by annealing zone-melted specimens of HgTe under various pressures of mercury. The Hall coefficient and resistivity were measured from 54°K to 300°K for both n- and p-type specimens in the 10^{16} to 5×10^{18}/cm^3 impurity concentration range. The electron Hall mobility of the purer HgTe specimens at 300°K is 17 000 cm^2/v-sec. Measured values of Hall coefficient at various magnetic fields and temperatures for two p-type specimens in the temperature range of the Hall crossover show the same qualitative behavior as was found for p-type InSb.[1] From the magnitudes of the extrinsic Hall coefficient and the Hall maximum, and the temperatures at which the Hall crossover and maximum occur, an electron-to-hole mobility ratio of 100 is calculated. The energy gap calculated from the Hall data of p-type and n-type HgTe is approximately 0.01 ev. The energy gap obtained from the resistivity slope is considerably larger (~0.1 ev) but since the mobility does not vary as $T^{-3/2}$, the latter value is probably too large. The purest specimen was opaque to infrared radiation between 1 μ and 30 μ.

* Work supported by an Engineering Research and Development Laboratory Contract.
[1] Harman, Willardson, and Beer, Phys. Rev. **95**, 699 (1954).

E3. Electrical Properties of n-Type HgTe. J. BLACK, S. KU, AND H. MINDEN, *Sylvania Electric Products.*—Single crystals of n-type HgTe have been prepared with carrier concentrations of 10^{17} cm^{-3}. The Hall coefficient R and resistivity ρ of these crystals have been measured at fields between 900 and 30 000 gauss from 80°K to 400°K. All specimens examined were intrinsic at 250°K. Between 250°K and 400°K the slopes of log ρ vs $1/T$ at zero magnetic field and of log R vs $1/T$ at low magnetic field corresponded to an apparent energy gap of about 0.08 ev. Below 140°K R leveled off to a constant value corresponding to a carrier concentration of 1×10^{17} cm^{-3}. The Hall electron mobility $R\sigma$ was about 15 000 cm^2/v-sec at room temperature and it increased to a maximum of about 19 000 cm^2/v-sec at 250°K. Below 250°K $R\sigma$ decreased and was proportional to $T^{1.4}$ between 160°K to 80°K. Above 280°K the Hall constant was independent of magnetic field B. Below 280°K R decreased with increasing magnetic field strength. The lower the temperature the greater was the variation of R with B; R at 80°K decreased by a factor of 20 between 900 and 30 000 gauss. Above about 250°K the magnetoresistance $\Delta\rho/\rho_0$ was proportional to B^2 up to fields of 30 000 gauss. Below 250°K $\Delta\rho/\rho_0$ fell below a B^2 dependence; as in the case of the Hall coefficient the magnitude of the deviation increased as the temperature decreased. Difficulties in the interpretation of these data will be discussed.

E4. Temperature Dependence of Absorption in p-Type Indium Arsenide. FRANK MATOSSI, *Naval Ordnance Laboratory.*—Recently, an absorption peak was observed in p-type InAs and attributed to transitions between the light and heavy hole bands.[1] This interpretation leads to the expectation that the peak will shift with temperature. Furthermore, the absorption should become stronger at lower temperatures. The absorption of several samples of InAs measured at different temperatures is in qualitative agreement with these expectations. The observed peaks are at about 0.17 ev for 300°K; 0.185 ev for 370°K; 0.19 ev for 420 and 460°K. At lower temperatures, the peak could not be clearly observed. The observations are compared with theoretical results calculated by F. Stern.

[1] F. Stern and R. Talley, Phys. Rev. **108**, 158 (1957).

E5. Extrinsic Photoconductivity in Nickel-Doped Germanium. R. NEWMAN AND W. W. TYLER, *General Electric Research Laboratory.*—Nickel at concentrations of 6.8×10^{15} cm^{-3} is introduced by diffusion at 850°C into germanium single crystals containing known arsenic concentrations. In samples for which $N_{As}<N_{Ni}$, the fraction, f, of lower Ni levels[1] occupied by electrons at low temperatures is controlled to about 10%. The spectral dependence of photoconductivity (at 77°K) for a series of p-type samples with f-values from 0.06 to 0.89 is interpreted in terms of hole excitation from neutral Ni sites and electron excitation from filled Ni sites (singly negative) into the conduction band. This interpretation is confirmed by photo-Hall measurements. The photoconductive yield for hole excitation process (at 0.3 ev) is shown to be proportional to $1-f/f$ in accordance with a simple theory. Absorption measurements on a p-type sample of low f-value and an n-type sample of high f-value ($N_{As}\sim2N_{Ni}$) show the same spectral dependence as photoconductivity spectra but permit estimates of absorption cross sections. At an energy of 0.5 ev these are $\sim10^{-16}$ cm^2 for both the photoionization of holes from neutral Ni sites or electrons from doubly charged Ni sites.

[1] Tyler, Newman, and Woodbury, Phys. Rev. **98**, 461 (1955).

E6. Photoresponse of Indium Antimonide to Short Pulses of Light. MILTON GREEN AND IRVING N. GREENBERG, *U. S. Army Signal Engineering Laboratories.*—Measurements of the photoresponse of polycrystalline n-type and single crystal p-type indium antimonide were made at 78°K, using short flashes of light from a high-voltage spark. With point contacts, the polycrystalline sample exhibited a photovoltaic effect which was larger than its photoconductive effect. With

soldered contacts, the opposite effect resulted. Silicon filters merely decreased the magnitude of both effects. A p-type single crystal was tested with a tungsten rectifying point contact, using unfiltered light. The photovoltaic effect was not observed but a large photoconductive effect was found. Applying a positive voltage to the point (negative bias) resulted in a very large photoconductive effect, as was expected. Reversing the bias caused a sharp decrease in photoconductivity. The response of the point contact photodiode was compared with a 929 phototube (red sensitive) and a 919 phototube (violet sensitive). It was found that the photodiode has a faster response time for this particular light flash, under the same external circuit time constant (0.01 microsecond), than either of the above phototubes or the polycrystalline sample.

E7. A New Photoelectromagnetic Effect in Germanium and Silicon. MANUEL CARDONA AND WILLIAM PAUL, *Harvard University.*—The quadratic P.E.M. effect observed by Kikoin and Noskov in cuprite has been observed in germanium and silicon. The effect occurs when the magnetic field B is rotated an angle ϕ about an axis lying in the illuminated face and perpendicular to the primitive direction of B. The linear effect is produced by the component $B\cos\phi$ of B, while the quadratic effect is produced by the action of $B\sin\phi$ on the electric current generated by $B\cos\phi$. From this elementary argument the quadratic P.E.M. effect should be proportional to $B^2\sin\phi\cos\phi$. A part of the effect is produced by the action of a magnetic field on a current produced by the action of a magnetic field on the diffusion current of the injected carriers. Calculating this term, one finds the same type of average of the collision time as appears in the magnetoresistance coefficients. Consequently, the effect becomes anisotropic and, instead of being proportional to $B^2\sin 2\phi$, is proportional to $B^2[\sin(2\phi+\Delta)+g]$ where Δ and g are functions of the constants of the semiconductor and the orientation of the sample. For certain simple orientations (such as the crystallographic axes) $\Delta=0$ and $g=0$. The ratio of the quadratic to the linear P.E.M. fields is, for small light intensities, a function only of the Hall angles, the magnetoresistance coefficients of electrons and holes, the impurity concentration, and the magnetic field.

E8. Low-Temperature Oscillatory Magneto-Absorption Under High Resolution.* S. ZWERDLING, B. LAX, AND L. ROTH, *Lincoln Laboratory.*—The fine structure of the oscillatory magneto-absorption of the direct transition in germanium predicted theoretically[1] has been observed experimentally. The experiments were carried out using magnetic fields up to 39 kilogauss, liquid helium temperatures, and an infrared grating spectrometer with useful resolving power greater than 20 000. With unpolarized radiation in the photon energy range 0.90 ev to 1.07 ev, approximately thirty absorption maxima were observed. Polarized infrared radiation with the electric vector first parallel then perpendicular to the magnetic field resolved considerable additional structure. The experimental data will be compared with theory. The application of the high-resolution, low-temperature system to other magneto-absorption experiments in semiconductors will also be discussed.

* The research reported in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.
[1] Roth, Lax, and Zwerdling, Bull. Am. Phys. Soc. 2, 141 (1957).

E9. Magnetoresistance Symmetry Relation for *N*-Germanium. COLMAN GOLDBERG AND W. E. HOWARD,* *Westinghouse Research Laboratories.*—If electrons are located in valleys that have rotational symmetry about the (111) axes in k-space and if there is no longitudinal magnetoconductance along the principal axes of a valley, the magnetoresistance coefficients should obey the symmetry relation $c/b=-1.00$. Careful magnetoresistance measurements on n-germanium in the temperature range 77°K to 300°K indicate that the relation is obeyed for carrier concentrations as high as 10^{16} cm^{-3} in contrast to previous measurements[1,2] which showed significant deviations from the symmetry relation for samples in the 10^{15} range at 77°K. Glicksman[1] has reported $c/b\approx+2$ for a carrier concentration of 5×10^{15} but the present measurements indicate that while deviations from the symmetry relation are observed at 77°K for samples in the range from 10^{15} to 10^{19}, c/b is always negative with an absolute value greater than unity. The values of the magnetoresistance anisotropy parameter determined from these magnetoresistance measurements are in agreement with values previously obtained from magnetoconductance measurements.[2]

* Present address: Physics Department, Harvard University.
[1] M. Glicksman, Bull. Am. Phys. Soc. Ser II, 2, 142 (1957).
[2] C. Goldberg, Phys. Rev. (to be published).

E10. Oscillatory Magnetoresistance in Mono- and Polycrystalline InAs. R. J. SLADEK, *Westinghouse Research Laboratories.*—Oscillations in the electrical resistivity of n-type InAs[1] resulting from longitudinal or transverse magnetic fields have been measured in both a single crystal sample ($n\approx7.6\times10^{16}$ cc^{-1}) and a *polycrystalline* sample ($n\approx2.8\times10^{16}$ cc^{-1}) at temperatures between 1.25°K and 20.2°K. Field strengths up to 29 000 gauss were employed. The occurrence of the effect in the polycrystal is a confirmation of the sphericity of the conduction band. In both samples the oscillations caused by transverse fields are similar to, but of larger amplitude than, those caused by longitudinal fields. The nodes of the oscillations are periodic in reciprocal field strength. The observed period in each sample agrees with that calculated from the electron concentration determined by Hall effect measurements. The amplitude of the oscillations in an exponential function of $-1/B$, where B is the magnetic field strength.[1] The temperature dependence of the amplitude of the oscillations in the single crystal fits the function $x/\sinh x$,[2] where $x=2\pi^2kT\hbar\omega$ and $\omega=eB/mc$, for an effective mass, $m=0.02m_0$; the temperature dependence of the oscillations in the polycrystal agrees approximately with this function.

[1] H. P. R. Frederikse and W. R. Hosler, Bull. Am. Phys. Soc. Ser II, 2, 347 (1957).
[2] P. N. Argyres, J. Phys. Chem. Solids (to be published).

WEDNESDAY AFTERNOON AT 2:00

Boston-Washington Room

(H. A. BOORSE presiding)

Cryogenics

EA1. (Abstract withdrawn.)

EA2. Magnetic Properties of Praseodymium Ethylsulfate at Low Temperatures. HORST MEYER,* *The Clarendon Laboratory, Oxford* (introduced by R. V. Jones).—The magnetic susceptibility of praseodymium ethylsulfate single crystals has been determined below 1°K using a single crystal of cerium magnesium nitrate as a thermometer. The praseodymium salt was thermally connected to the thermometer by silver strips. A separate series of experiments on temperature equilibrium and thermal transfer between a paramagnetic salt and a silver ribbon were carried out and it was shown that under our experimental conditions direct temperature measurements could be made down to about 0.09°K. The lowest level of Pr^{3+} in the ethylsulfate is not a Kramers' doublet but its small splitting follows a two-dimensional Gaussian distribution.[1] Our measurements showed that between 1.2 and 4.2°K the susceptibility follows Curie's law with a value of $g_{11}=1.56$. By fitting the theoretical curve to the experimental one below 1.2°K, the most probable splitting was found to be $\Delta_0/k=0.5$°K, which is close to the value obtained from specific heat measurements.[2]

* Now at the Division of Engineering and Applied Physics, Harvard University.
[1] J. M. Baker and B. Bleaney, Proc. Phys. Soc. (London) **68**, 936 (1955).
[2] Horst Meyer and P. L. Smith, Proc. of the 5th Low Temp. Conf. (Madison, 1957).

EA3. Galvanomagnetic Properties of Ga Single Crystals at Helium Temperatures.* J. YAHIA AND J. A. MARCUS, *Northwestern University.*—Measurements of the Hall effect and magnetoresistance have been continued on two "thick" crystals (~0.7 mm thick) for which the alignment of the crystallographic axes with the current and field is within 2°. Table I gives the Hall coefficients obtained for these crystals.

TABLE I.

Crystal	Orientation of J,B	$\frac{\rho 4.2°K}{\rho 279°K}$	$A_{4.2°K(cm/c)}$	$A_{77°K(cm/c)}$	$A_{279°K(cm/c)}$
ba	$J\|$b-axis, $B\|$c-axis	3.52×10^{-4}	-11.9×10^{-3}	-6.2×10^{-3}	-4.3×10^{-3}
cb	$J\|$c-axis, $B\|$b-axis	3.26×10^{-4}	-11.8×10^{-3}	-5.9×10^{-3}	

As for crystals *ac*[1,2] and *ab*,[2] oscillations of the de-Haas v. Alphen type were observed in the magnetoresistance and the Hall coefficient at 10kg and 1.4°K. The oscillations were roughly periodic in $1/B$ and in phase for crystal *ba*. An average period for these oscillations is $15\times10^{-7}\,G^{-1}$. For crystal *cb* the oscillations in magnetoresistance were periodic in $1/B$ with period $25\times10^{-7}\,G^{-1}$. The oscillations in Hall Coefficient were too small to warrant a good estimate of their period or phase relation to the magnetoresistance oscillations.

* Supported by the National Science Foundation.
[1] J. Yahia and J. A. Marcus, Bull. Am. Phys. Soc. Ser. II, **2**, 184 (1957).
[2] J. Yahia and J. A. Marcus, Proc. 5th Internatl. Conf. on Low Temperature Phys. and Chem. (August, 1957) (to be published).

EA4. Specific Heat of Zinc in the Normal and Superconducting States.* G. SEIDEL AND P. H. KEESOM, *Purdue University.*—The specific heat of zinc has been measured in the temperature range from 0.4°K to 4.2°K, temperatures below 1°K being obtained by pumping on a bath of He^3. Results above the superconducting transition temperature of 0.90°K yield $\theta=302$°K and $\gamma=0.63$ millijoule/mole (°K)^2 which agree quite well with previous work. Below 0.7°K the electronic heat can be represented by an equation of the form $C_{es}=10\gamma T_c e^{-1.5}(Tc/T)$. The constants in this equation are comparable to those found for vanadium[1] and tin.[2] For determining the electronic specific heat in the superconducting state zinc has the advantage that below the transition temperature the lattice specific heat is less than 4% of the total. However, because of the low transition temperature, values of T_c/T could be obtained only up to 2.2. The measurements indicate the magnitude of the discontinuity in the specific heat at the transition temperature to be 0.74 millijoule/mole (°K) whereas the value calculated from the slope of the threshold field curve[3] yield 0.97 millijoule/mole (°K).

* This work was supported by a Signal Corps contract.
[1] Corak, Goodman, Satterthwaite, and Wexler, Phys. Rev. **102**, 656 (1956).
[2] Corak and Satterthwaite, Phys. Rev. **102**, 662 (1956).
[3] Goodman and Mendoza, Phil. Mag. **42**, 594 (1951).

EA5. Coherent Excited States in the Theory of Superconductivity. P. W. ANDERSON, *Bell Telephone Laboratories.*—We discuss here two types of coherent excited states in the Bardeen, Cooper, and Schrieffer[1] theory of superconductivity. The first type is vital to the understanding of the Meissner effect and its gauge invariance. They are the states generated by the momentum displacement operator $\Sigma_s \exp(i\mathbf{q}\cdot\mathbf{r}_s)$, and may be described either as excited Cooper pair states[2] with nonzero momentum or as plasma oscillations. We show that without taking into account long-range Coulomb forces they lie in the energy gap; with plasma effects they become the plasma oscillations, with equations of motion unaffected by the energy gap. Our discussion clarifies both the difference between the insulator and the superconductor, and the reason for the B.C.S. $q=0$ pairing condition. The second type certainly lies in the energy gap. They follow from a discussion of the B.C.S. reduced Hamiltonian in terms of an equivalent spin Hamiltonian. They might be described as vibrational modes of the sea of $q=0$ pairs. The semiclassical nature of the B.C.S. solution and the reason for its accuracy are made clear by this discussion.

[1] Bardeen, Cooper, and Schrieffer, Phys. Rev. **106**, 162 (1957); Phys. Rev. (to be published). We shall call this B. C. S. hereafter.
[2] L. N. Cooper, Phys. Rev. **104**, 1189 (1956).

EA6. Cryostat for Nuclear Polarization.* H. MARSHAK, C. A. REYNOLDS,† F. J. SHORE, AND V. L. SAILOR, *Brookhaven National Laboratory.*—A large cryostat has been constructed for the polarization of nuclei by the brute force method The

system employs two stages of adiabatic demagnetization with superconducting heat switches linking the various components. This permits recycling of the stages allowing continuous operation of the sample at low temperatures for relatively long periods of time. Liquid nitrogen cooled solenoids provide the necessary magnetic fields. Design parameters and initial performance characteristics will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Guest Scientist from the University of Connecticut.

Invited Paper

EA7. Excitation of Rotons in Helium II by Cold Neutrons. H. PALEVSKY, *A. B. Atomenergi, Stockholm* (guest scientist from *Brookhaven National Laboratory*). (30 min.)

WEDNESDAY AFTERNOON AT 2:00

Panel Room

(RICHARD WILSON presiding)

Invited Paper

F1. Experiments with Polarized Neutrons and the Optical Model of the Nucleus. H. H. BARSCHALL, *University of Wisconsin.* (30 min.)

Neutron Physics II

F2. Total Neutron Cross Sections of C^{12} and C^{13}. H. B. WILLARD, J. K. BAIR, AND H. O. COHN, *Oak Ridge National Laboratory.*—Levels observed in the $C^{13}(d,p)C^{13}$ reaction[1] indicate that resonances could appear in the total neutron cross section of C^{13} at 2.73 and 2.80 Mev. Measurements in this region have been made with good geometry and 5 kev energy resolution. The data obtained do not deviate by more than ±0.2 barn from the average value in this region. Levels in C^{14} have not previously been investigated by means of the $C^{13}+n$ interaction. Barium carbonate, enriched to 61.7% in C^{13}, was converted to elemental carbon. Samples sufficiently large for transmission measurements were prepared by pressing the amorphous carbon into a thin-walled nickel can. Total neutron cross sections from 0.2 to 3 Mev were obtained by experimental subtraction with a duplicate nickel can containing an equivalent amount of C^{12}. The nonresonant cross section decreases smoothly from about 3 barns at 0.2 Mev to 1 barn at 3 Mev. With an average resolution of about 7 kev, only three resonances were observed. These occurred at 1.75 Mev, width 25 kev, and 2.43 Mev and 2.45 Mev. The latter levels interfere strongly, the widths being the order of 15 kev.

[1] McGruer, Warburton, and Bender, Phys. Rev. 100, 235 (1955).

F3. Neutron Strength Functions for Iodine from Fast Neutron Capture Cross Sections.* P. A. MOLDAUER, *Argonne National Laboratory.*—The capture cross section of iodine for neutrons of 10 to 600 kev has been calculated by averaging over Breit Wigner resonances. Low energy experimental data were used for the radiation and *s*-wave neutron widths and the Lang and LeCouteur formula for the level spacings. The remaining parameters were adjusted to fit experimental capture cross sections at 25 kev[1] and in the hundred kev region.[2] The fit in the latter region was consistent with the assumption of equal inelastic and elastic strength function for equal l values. Fitting the 25 kev cross section led to the following results for the relative magnitudes of the *s*, *p*, and *d* wave strength functions: $S_p \approx 0.25 S_s$, $S_d \approx 25 S_s$. The latter agrees qualitatively with the prediction of a *d* wave resonance by the complex well model.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Macklin, Lazar, and Lyon, Phys. Rev. 107, 504 (1957).
[2] Martin and Taschek, Phys. Rev. 89, 1302 (1953) and Supplement No. 1 to BNL 325 (1957).

F4. Resonances in the Total Neutron Cross Section of Neon. H. O. COHN AND J. L. FOWLER, *Oak Ridge National Laboratory.*—The total neutron cross section of neon of natural abundance was measured for neutron energies from 0.8 to 1.9 Mev by a transmission experiment. $Li^7(p,n)Be^7$ neutrons were produced at a Li rotating target with protons from the ORNL 5.5-Mv Van de Graaff. The detector was a 1-atmos-propane recoil counter. A 39 in. long and ¾ in. diameter thin walled ($\frac{1}{16}$ in.) stainless steel tube filled to 1200 lb/in.[2] neon gas served as the scattering sample. A similar tube, but evacuated, was used to correct experimentally for the effect due to the stainless steel. The resulting cross-section curve, corrected for the second group neutrons from the $Li^7(p,n)Be^7$ reaction, together with angular distribution measurements[1] shows resonances at the following energies (in Mev) with tentative spin and parity assignments given in parenthesis: 0.91 (3/2−), 1.27 (?), 1.31 (1/2−), 1.37 (3/2+), 1.62 (3/2−), 1.68 (3/2+), and 1.85 (?).

[1] H. O. Cohn and J. L. Fowler, Bull. Am. Phys. Soc. Ser. II, 1, 175 (1956).

F5. Inelastic Neutron Scattering in Mn^{55}.* M. A. ROTHMAN, D. M. VAN PATTER, N. NATH,† AND C. E. MANDEVILLE, *Bartol Research Foundation.*—A 100-channel pulse-height analyzer and a slow-fast coincidence circuit has been used to observe gamma-gamma coincidences arising from inelastic neutron scattering in Mn^{55}, using neutron energies up to 2.5 Mev. Gamma rays of energy 0.848±0.008, 1.165±0.015, 1.41±0.03, 1.78±0.02, and 2.31±0.02 were found in coincidence with the 128-kev gamma ray from the first excited state. It was found that effects of multiple neutron scattering

produced coincidences between the gamma rays from Mn and those from the iodine of the scintillator. Precautions taken to avoid these effects will be discussed.

* Assisted by the U. S. Atomic Energy Commission.
† On leave of absence from the University of Delhi.

F6. Total Neutron Cross Section Measurements of Ca, Sr, Na, and K.* E. H. MAGLEBY, *Phillips Petroleum Company.*—Total neutron cross section measurements have been made on Sr, Ca, Na, and K, with the Materials Testing Reactor crystal spectrometer and fast chopper. Pure metallic samples were prepared for the measurements on Ca, Na, and K. Carbonate and nitrate samples were used for the Sr measurements. Data were taken in the energy region 0.02 to 10 000 ev. Previously unreported resonances are observed in Sr at approximately 660 and 750 ev, with indication of resonances at 1050 and 3200 ev. One and possibly two resonances are observed in the vicinity of 1000 ev in Ca. Some structure is observed in K between 1000 and 10 000 ev.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

F7. Neutron Velocity Spectrometer Results Using a 2000-Channel Analyzer.* J. S. DESJARDINS, J. ROSEN, E. MELKONIAN, L. J. RAINWATER, AND W. W. HAVENS, JR., *Columbia University.*—Self-detection and transmission measurements of Ta, Cd, and NaBr have been made using the new 2000-channel analyzer. Measurements were taken with detector gate widths of 0.2 μsec and 0.1 μsec using the regular path length of 35.22 m. With these detector gate widths the resolution is better than 0.01 and 0.005 μsec/m for the higher energy neutrons. Results obtained with this apparatus are being analyzed using the IBM 650 computer, and the results of this analysis will be presented.

* This work was partially supported by the U. S. Atomic Energy Commission.

F8. Identification of Level Spins by Total Cross-Section Measurements.* R. E. CHRIEN AND R. L. ZIMMERMAN, *Brookhaven National Laboratory.*—The spins of virtual levels in the compound nucleus, excited by S-wave neutrons, can be inferred from area or shape analysis of total neutron cross-section data under certain favorable conditions. These conditions are met in a level whose neutron width, Γ_n is comparable or larger than its radiation width, Γ_γ. A thick-thin area analysis gives Γ and $g\Gamma_n$. If an approximate value for Γ_γ is known, and if Γ_n for the level is sufficiently large, then g may be determined by a comparison of $\Gamma-\Gamma_\gamma$ with $g\Gamma_n$. Several levels in the target nucleus $W^{182}(I=\frac{1}{2})$ have been examined with this technique. Preliminary analysis of the data for two target thicknesses give $g=0.21\pm0.10$ for the 46-v level and $g=0.80\pm0.42$ for the 27-v level, indicating $J=0(g=\frac{1}{2})$ and $J=1(g=\frac{3}{2})$, respectively. Analysis of more data is proceeding in an attempt to reduce the quoted error and extend the method to other levels.

* Work performed under contract with U. S. Atomic Energy Commission.

F9. Nuclear Radius from Potential Scattering of Neutrons.* K. K. SETH, D. J. HUGHES, R. L. ZIMMERMAN, AND R. C. GARTH, *Brookhaven National Laboratory.*—The potential scattering cross section has been measured for a number of elements whose atomic weights range between 64 and 238. Each value was obtained by subtracting the effects of nearby resonances from a total cross-section measurement made between resonances in the energy region where resonances are clearly resolved. In some cases the value of the potential scattering cross section obtained in this way was compared with the value obtained by an averaging method in the kev region. The latter method makes use of the fact that, for a thick sample, all resonance neutrons are eliminated from the beam, and a further increase in the thickness attenuates the beam by potential scattering only. There was consistent agreement in the cases in which both methods were employed. An earlier comparison to calculations with the Feshbach-Porter-Weisskopf optical model assuming spherical nuclei showed that there were qualitative discrepancies around $A=160$. Chase, Wilets, and Edmonds have recently had better success in explaining these experimental results using the optical model and the measured nuclear deformations and have found that the nuclear radius varies with atomic weight in a more complicated way than was predicted originally.

* Work performed under contract with the U. S. Atomic Energy Commission.

F10. Neutron Strength Functions.* R. L. ZIMMERMAN AND D. J. HUGHES, *Brookhaven National Laboratory.*—The neutron strength function, Γ^0_n/D, has been measured for a number of elements and isotopes with atomic weights ranging from 90 to 238. The values were obtained with the BNL fast chopper both by detailed resonance analysis and by an averaging method in which a measurement of the average cross section in the kev region yields the strength function directly. In the individual cases where both methods were employed, the consistent agreement shows that the strength function measured in the kev region is the same as that measured at the relatively low energies where levels can be resolved. Neutrons of higher angular momenta are not expected to contribute significantly to the cross section in the energy regions we have considered. Special emphasis was given the measurements on rare earth elements for which it is expected that nuclear deformation will cause the strength function values to vary with atomic weight in a more complicated way than was first predicted by the Feshbach-Porter-Weisskopf "cloudy crystal ball" model assuming spherical nuclei.[1] The results will be compared with recent calculations by D. M. Chase and L. Wilets in which the nuclear deformations are taken into account.

* Work performed under contract with the U. S. Atomic Energy Commission.
[1] Feshbach, Porter, and Weisskopf, Phys. Rev. 96, 448 (1954).

F11. Second-Order Contamination in a Neutron Crystal Spectrometer.* R. HAAS† AND F. J. SHORE, *Brookhaven National Laboratory.*—The beam obtained in the Bragg reflection of neutrons from a crystal lattice is not monochromatic because of the presence of higher order reflections. These may be minimized by proper choice of crystal type and planes, yet even under the most favorable conditions an appreciable contamination results. This residual contamination requires corrections to be made for precise cross-section measurements or determination of incident neutron spectrum. Holm[1] has treated theoretically the second-order reflectivity from a crystal. However, there has been no adequate experimental verification published. Results of the experimental determination of the second-order contamination from 0.1 ev to 5 ev for Be and NaCl crystals will be reported. These results are consistent with Holm's calculations if the pile spectrum, counter response, and crystal reflectivity are properly considered. This allows one to calculate the second-order contamination when pile spectrum changes are made.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Guest Scientist from Technische Hochschule, Munich.
[1] M. W. Holm, Scattering of Slow Neutrons by Be and NaCl Crystals, IDO 16115, Phillips Petroleum Company.

WEDNESDAY AFTERNOON AT 2:15

Terrace Room

(L. M. CORLISS presiding)

Division of Solid-State Physics

G1. Electron-Diffraction Studies of Single Crystals. J. A. IBERS, *Shell Development Company.* (30 min.)

G2. Intensities in Electron-Diffraction Patterns from Crystalline Materials. LORENZO STURKEY, *Dow Chemical Company.* (30 min.)

G3. Single-Crystal Neutron-Diffraction Studies of Antiferromagnetism at Low Temperatures with Applied Magnetic Fields. W. C. KOEHLER, *Oak Ridge National Laboratory.* (30 min.)

G4. Antiferromagnetic Structures and Related Domain Properties As Studied by Neutron-Diffraction Techniques at Low Temperatures. M. K. WILKINSON, *Oak Ridge National Laboratory.* (30 min.)

WEDNESDAY AFTERNOON AT 2:00

Grand Ballroom

(H. M. FOLEY presiding)

Theoretical Physics II: Particles

GA1. Universal Fermi Interaction and Radiative Beta Decay of the Pion.* E. C. G. SUDARSHAN† AND R. E. MARSHAK, *University of Rochester.*—We have shown[1] that the imposition of the requirement of chirality invariance on the four-fermion interaction Hamiltonian yields the unique axial vector (A) plus vector (V) universal Fermi interaction. All of the parity breakdown experiments in beta decay and muon decay can be explained by the $A+V$ interaction by reversing the helicity of the neutrino, including the recent experiment on the electron polarization in muon decay.[2] Another test of this theory is provided by the radiative beta decay of the pion. The $A+V$ interaction leads to a convergent transition probability for this process, namely 80 sec^{-1}. This value is completely consistent with the latest experiment.[3] Our conclusion differs from that of Treiman and Wyld[4] and hinges on whether the electron-neutrino angular correlation experiment for He^6 is in error.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at Harvard University.
[1] E. C. G. Sudarshan and R. E. Marshak, Proc. of Padua-Venice Conference, September, 1957.
[2] Culligan, Frank, Holt, Kluyver, and Massam, University of Liverpool preprint.
[3] Cassels, Rigby, Wetherell, and Wormald, Proc. Phys. Soc. (London) **70**, 729 (1957).
[4] S. B. Treiman and H. W. Wyld, Phys. Rev. **101**, 1552 (1956).

GA2. Symmetry Principle for the Four-Fermion Interaction.* S. A. BLUDMAN, *University of California, Berkeley.*—The hypothesis of a universal form of interaction $f\bar{\psi}\gamma_\mu(1+\gamma_5)\psi\bar{\psi}\gamma_\mu(1+\gamma_5)\psi$ between any four fermions (with or without precise equality of the coupling constants in β and μ decay) is now, thanks to recent experiments, more promising than ever before. In the absence of strong meson interactions and of fermion mass, a theory involving only the foregoing interaction and the electromagnetic interaction $e\bar{\psi}\gamma_\mu\psi A_\mu$ would admit the gauge transformations $\psi\to\exp[i\alpha f(1+\gamma_5)]\psi$ on all Fermi particles. This symmetry principle would lead to a conservation law for fermions and the exact equality of the coupling constant in all four-fermion processes. The role of the strong mesonic interactions, which distinguish baryons from leptons, and to which in this picture the fermion mass is attributed directly or indirectly, is discussed. In particular, the questions of an absolute lepton-conservation law and of a universal strength of interaction $g=f^2$ are considered.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

GA3. Single Particle Energies in Brueckner's Nuclear Matter Theory.* D. J. THOULESS, *Cornell University.*—The removal of one particle with momentum $\mathbf{k}_P$ from nuclear matter at constant volume alters the reaction matrix used in Brueckner's calculations.[1] An expansion of this change can be made, which with neglect of three particle clusters gives

$$\langle \mathbf{k}_1\mathbf{k}_2|\delta G|\mathbf{k}_1\mathbf{k}_2\rangle = |\langle \mathbf{k}_1\mathbf{k}_2|G|\mathbf{k}_P\mathbf{k}_3\rangle|^2 \{E(k_P)+E(k_3)-E(k_1)-E(k_2)\}^{-1},$$

where $\mathbf{k}_1$, $\mathbf{k}_2$ are inside the Fermi sea, $\mathbf{k}_3$ is outside it and $\mathbf{k}_P$ is on the Fermi surface; momentum is conserved by the G matrix. The sum over all $\mathbf{k}_1$, $\mathbf{k}_2$ gives a positive correction to the energy independent of the volume. This may account for the difference between the average energy per particle and the Fermi energy; they should be equal at equilibrium density,[2] but differ by about 10 Mev in Brueckner's calculations. The effective mass will be raised by this correction.

* Supported in part by the joint program of the Office of Naval Research and U. S. Atomic Energy Commission.
[1] K. A. Brueckner and J. L. Gammel, Phys. Rev. **105**, 1679 (1957), and private communications.
[2] H. A. Bethe, Phys. Rev. **103**, 1353 (1956).

GA4. Λ-Nucleon Interaction in the Hypertriton. B. W. DOWNS,* *Cornell University,* AND R. H. DALITZ, *University of Chicago.*—An upper bound for the strength of the Λ-nucleon interaction effective in the hypertrition is found by a variational method, as function of the Λ binding in the hypertriton. The six-parameter trial function used has sufficient flexibility to allow strong correlations between the particles while having an asymptotic form appropriate to the weak binding. The upper bounds obtained are of order 10% lower than

those obtained earlier[1,2] with a Feshbach-type wave function and are not compatible with the existence of a bound hyperdeuteron unless the spin dependence of the Λ-nucleon interaction is very much stronger than other evidence indicates.[3] The existence of $_{\Lambda}He_2$ is also incompatible with these upper bounds. Features of the two-body decay of the hypertriton will also be discussed on the basis of this wave function.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] B. W. Downs, Bull. Am. Phys. Soc. Ser. II, 2, 175 (1957).
[2] R. H. Dalitz, Repts. Progr. Phys. 20, 163 (1957).

Invited Papers

GA5. The Nucleon-Antinucleon Interaction. G. F. CHEW, *University of California, Berkeley.* (30 min.)

GA6. Theory of Heavy Ion Nucleon Transfer Reactions. GREGORY BREIT, *Yale University.* (30 min.)

WEDNESDAY AFTERNOON AT 4:45

Terrace Room

(H. D. SMYTH presiding)

Business Meeting of the American Physical Society

THURSDAY MORNING AT 9:45

Boston-Washington Room

(S. MILLMAN presiding)

Nuclear Moments: Nuclear Resonances

H1. Nuclear Spin and Hyperfine Structure of 2.6-hr Mn^{56}.* W. J. CHILDS AND L. S. GOODMAN, *Argonne National Laboratory.*—The atomic beam magnetic resonance technique[1,2] has been used to measure the nuclear spin and hyperfine structure of 2.6-hr Mn^{56}. The nuclear spin is found to be $3\hbar$. The sample was prepared by neutron capture in the Argonne research reactor. Nonradioactive gallium metal, mixed with the manganese in the oven, was used both for alignment of the beam and for calibration of the homogeneous magnetic field.

* This work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. R. Zacharias, Phys. Rev. 61, 270 (1942).
[2] L. S. Goodman and S. Wexler, Phys. Rev. 99, 192 (1955).

H2. Nuclear Spin and Hyperfine Interaction of Radioactive Ga^{72}.* L. S. GOODMAN AND W. J. CHILDS, *Argonne National Laboratory.*—The nuclear spin and hyperfine interaction of 14.1-hr Ga^{72} have been measured by the atomic beam magnetic resonance method.[1,2] The measured spin, $I=3\hbar$ and hyperfine interaction, $\Delta\nu=144.8\pm0.8$ mc/sec allow one to calculate an apparent magnetic moment $|\mu|=0.12$ nm. Some interesting details of the observed resonances will be discussed.

* This work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. R. Zacharias, Phys. Rev. 61, 270 (1942).
[2] L. S. Goodman and S. Wexler, Phys. Rev. 99, 192 (1955).

H3. Quadrupole Coupling of Solid Cyanogen Chloride.* P. A. CASABELLA AND P. J. BRAY, *Brown University.*—The nuclear quadrupole resonances of N^{14} and Cl^{35} have been observed in solid ClCN. At 77°K the N^{14} coupling constant is 3.219 Mcps and the field gradient asymmetry parameter is 1.57%. The Cl^{35} coupling constant is 83.472 Mcps, also at 77°K, assuming that the asymmetry parameter is zero. In the course of the study of the N^{14} resonances a detailed study was made of the shape of the negative wings which occur when Zeeman modulation and phase sensitive detection are used. The shape of these wings can reveal whether two resonances are due to two nonequivalent positions of the N^{14} nuclei, or one position with a nonzero asymmetry parameter. A theoretical expression has been derived for the shape of the wings which agrees with the observed shape. The coupling constants of the Cl^{35} and N^{14} nuclei were interpreted in terms of hybrid structures which had been used for BrCN[1] and ICN,[2] but these gave unsatisfactory results. An additional ionic hybrid structure has been added and found to give satisfactory results for ClCN, BrCN, and ICN.

* Work supported by a Frederick Gardner Cottrell Grant from the Research Corporation.
[1] S. Geller and A. L. Schawlow, J. Chem. Phys. 23, 779 (1955).
[2] C. H. Townes and B. P. Dailey, J. Chem. Phys. 20, 35 (1952).

H4. Nuclear Magnetic Resonances of B^{11} and Li^7 in the Binary Glass Li_2O–B_2O_3.* A. H. SILVER,† J. G. O'KEEFE, AND P. J. BRAY, *Brown University.*—A previous study[1] by nuclear magnetic resonance methods of B^{11} in a Na_2O–B_2O_3 glass has been extended to a similar study of the binary glass $Li_2O-B_2O_3$. The nuclear magnetic resonances of B^{11} and Li^7 have been studied in lithium oxide–boric oxide glass as a function of the Li_2O concentration. The spectrum for the B^{11} consists of a narrow line superimposed on a broad line spectrum which arises from the distortion of the $m=\frac{1}{2}\rightarrow-\frac{1}{2}$ transition by a second-order quadrupole interaction. The relative intensity of the narrow line increases from zero in 100% B_2O_3 and the intensity of the broad line decreases with an increase in Li_2O concentration. The width of the broad resonance does not change measurably with composition.

Excess oxygen from the Li_4O changes the coordination number of some of the boron atoms from 3 to 4, reducing the quadrupole interaction in these cases and producing the narrow line. The Li^7 resonance also has been observed. Preliminary investigations have shown only a single symmetric line.

* Research supported by the U. S. Atomic Energy Commission.
† Present address: Ford Motor Company.
[1] Silver, O'Keefe, and Bray, Bull. Am. Phys. Soc. Ser. II, 2, 225 (1957).

H5. Nuclear Magnetic Resonance Studies of Pile-Irradiated NaI and KI.* P. J. Bray and John F. Hon,† *Brown University.*—Nuclear magnetic resonance (NMR) studies have been made of NaI and KI single crystals both before and after irradiation in the Brookhaven reactor. The numbers of defects (vacancies plus interstitials) estimated from the decrease of intensity of the I^{127} line in NaI and KI crystals which received an integrated fast neutron flux of 4.1×10^{17} nvt at room temperature (or somewhat above) are: NaI, 3.7×10^{-4} defect/atom; KI, 2.3×10^{-4} defect/atom. The values predicted by the methods of Seitz and Koehler[1] are 8.2×10^{-4} and 5.6×10^{-4} defect/atom, respectively. No radiation-induced change in the Na^{23} resonance is discernible. The defect density from the I^{127} data may be underestimated due to overlapping of the volumes affected per defect. Some degree of annealing is probable. The defect density estimated from the intensity decrease of the I^{127} line in KI crystals which received an integrated fast neutron flux of 2.0×10^{17} nvt at 0°C (or somewhat below) is 3.5×10^{-4} defect/atom. A value of 2.8×10^{-4} defect/atom is predicted by the methods of Seitz and Koehler.[1]

* Research supported by the U. S. Atomic Energy Commission.
† Now at Atomics International.
[1] F. Seitz and J. S. Koehler, *Solid State Physics* (Academic Press, Inc., New York, 1956), Vol. II.

H6. Nuclear Magnetic Resonance and Dislocations in NaI and KI.* John F. Hon† and P. J. Bray, *Brown University.*—A study of the intensity of the I^{127} nuclear magnetic resonance line in single crystals of NaI[1] and KI[1] as a function of the orientation of the polarizing field, H_0, with respect to the crystallographic axes has revealed an anomalous increase in intensity when H_0 is in a (1,0,0) type direction. In the case of NaI the intensity increases by a factor of about 2.4. The intensity increase in KI is less pronounced. These anomalies can be explained by the effects of quadrupole interactions due to the strains produced by dislocations. The angular dependence of the quadrupolar splitting of the nuclear magnetic resonance line resulting from the strains produced by an edge type dislocation has been calculated by Watkins.[2] This calculation has been extended to screw type dislocations. The results indicate a strong tendency for dislocation lines of both types to be preferentially aligned in (1,0,0) type directions.

* Research supported by the U. S. Atomic Energy Commission.
† Now at Atomics International.
[1] These crystals were obtained from the Harshaw Chemical Company.
[2] G. D. Watkins, Ph.D. thesis, Harvard University, 1952.

H7. Nuclear Magnetic Shielding of F^{19} in Some Fluorocarbons.* T. S. Smith, *Ohio University and Goodyear Atomic Corporation,* and E. A. Smith, *Goodyear Atomic Corporation.*—The positions of the nuclear magnetic resonance lines of the various equivalent F^{19} groups in 1,1-dichloro-1,-2,2,2-tetrafluoroethane (CCl_2FCF_3); 1,2-dichloro-1,1,2,2-tetrafluoroethane ($CClF_2CClF_2$); 1,1,2-trichloro-1,2,2-trifluoroethane (CCl_2FCClF_2); trichlorofluoromethane (CCl_3F); perfluorodimethylcyclohexane (C_8F_{16}); and 2,2,3 trichloroheptofluorobutane ($CF_3CCl_2CClFCF_3$) have been measured with respect to the F^{19} line of trifluoroethanoic (CF_3COOH) acid. The experimental work was done with a Varian Associates NMR Spectrometer Model V4300 A. Calibration was achieved by side-band techniques and relative positions were obtained by direct substitution of samples during the field sweep. This method permitted relative positions of most lines to be determined to ±1 milligauss. Previous work[1] has shown that the nuclear magnetic shielding constant for F^{19} in fluoromethanes decreases with an increase of the total electronegativity of the molecule. The present work shows a similar influence due to the atoms attached to the neighboring carbon atom.

* This work performed under Goodyear Atomic Corporation contract with the U. S. Atomic Energy Commission.
[1] L. H. Meyer and H. S. Gutowsky, J. Phys. Chem. 57, 481 (1953).

H8. Temperature Dependence of Nuclear Spin Relaxation and Diffusion in Water.* J. H. Simpson† and H. Y. Carr, *Rutgers University.*—The activation energies E_R and E_D of nuclear spin relaxation T_1 and translational self-diffusion D have been obtained for protons in water using nuclear magnetic resonance free precession techniques. These energies have been compared with E_V, the activation energy of T/η where T is the absolute temperature and η is the viscosity. E_R, E_D, and E_V are equal and approximately constant in the region 5–25°C. The three values decrease in the region 35–55°C. E_R decreases at a rate greater than that of E_D and E_V. In the region 65–100°C, E_D and E_V are constant and equal just within the experimental error; however E_R, although constant, has a value 16% less than that of E_V. This difference is well outside the experimental error. This information provides a basis for re-examination of the theories of liquid structure, the Bloembergen-Pound-Purcell theory of relaxation, the Stokes-Einstein relation, and various properties of water having anomalies near 40°C.

* This work was supported in part by the U. S. Air Force Office of Scientific Research and the Rutgers Research Council.
† Now at the University of Delaware.

H9. Reaction Rates by Nuclear Magnetic Resonance.* Harden M. McConnell, *California Institute of Technology.*—The Bloch equations are modified to describe the magnetic resonance of a nucleus X which is transferred back and forth between two (or more) magnetic environments (A,B) by kinetic molecular processes. These equations are easily solved to give previously derived relations between chemical exchange rate and line shape for the case of slow passage and no rf saturation.[1] Under a number of other limiting conditions the modified equations can also be solved to yield useful relations between exchange rate and line shape. Limiting cases include conditions where, e.g., (a) A is diamagnetic, B is paramagnetic with large X hyperfine interaction; (b) there is strong X nuclear electric quadrupole relaxation in A but not in B; (c) there is rf saturation; (d) there is fast passage. Condition (d) has been employed in an experimental study of proton exchange rates in aqueous solutions of the ammonium ion.

* Sponsored by the National Science Foundation.
[1] Gutowsky, McCall, and Slichter, J. Chem. Phys. 21, 279 (1953).

H10. Chemical Shifts of N^{14} in NMR Spectra of Ammonia and Related Compounds.* Bernhard M. Schmidt, L. Carlton Brown, and Dudley Williams, *The Ohio State University.*—The nuclear magnetic resonances of N^{14} in ammonia and related compounds have been studied in a field $H_0 = 10\,730$ gauss. Shifts of the resonances relative to the peak associated with N^{14} in the NH_4^+ ions in a saturated aqueous solution of NH_4NO_3 have been measured for the following compounds: HN_4Cl, NH_4Br, NH_4I, $NH_4H_2PO_4$, $(NH_4)_2S$, $NH_4SO_4\cdot ZnSO_4\cdot 6H_2O$, NH_4SCN, ammonium hydroxide, NH_3 liquid, NH_3 dissolved in ethanol, $Ag(NH_3)_2NO_3$, $Zn(NH_3)_6Cl$, $Ca(NH_3)_8Cl_2$, $N(CH_3)_4Cl$, $N(CH_3)_4Br$, and $NH(CH_3)_3$. Mixtures of ammonion salt solutions with ammonium hydroxide have also been studied. The relative widths of the resonance peaks have been determined. Experimental details are given in the paper. The N^{14} peak in ammonium hydroxide bears a closer resem-

blance to the N^{14} peaks in liquid NH_3 and in ethanol solutions of NH_3 than to the N^{14} peaks in solutions of ammonium salts. The structure of ammonium hydroxide is discussed in the light of the data presented.

* Supported by the Office of Naval Research.

H11. Magnetic and Pure Quadrupole Resonance of N^{14} in Solid Nitrogen.* F. W. TERMAN AND T. A. SCOTT, *Harvard University.*—The N^{14} magnetic and pure quadrupole resonances have been studied in solid N_2. Below 35.4°K the crystal is f.c.c.; above it is c.p.h. and the molecules are known to rotate.[1] The sample was one liter of nitrogen gas which was liquified and frozen in a closed system. A Pound-Watkins spectrometer and magnetic field modulation were used. The magnetic resonance observed in 7 kilogauss just below the triple point was a doublet. Rotation of the sample varied the splitting in the expected manner for a single crystal. The apparent e^2qQ/h is 6.6 kc at 62°K, dropping to 5.4 kc at 53°K. Below the latter temperature the signal became lost in the noise. An intense pure quadrupole resonance was observed at 4.2°K. The value of e^2qQ/h, 4,650±1 kc, is close to that found in other triply bonded nitrogen compounds.[2] Its temperature dependence is being studied. This strong interaction in the fixed molecule is presumably averaged out in the high-temperature phase. The residue is ascribable to the noncubic symmetry of the nuclear environment.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] B. Ruhemann, Z. Physik **76**, 368 (1932).
[2] C. H. Townes and B. P. Dailey, J. Chem. Phys. **17**, 782 (1949).

H12. Nuclear Magnetic Resonance in Adsorbed Molecular Layers from 15 to 90°K. R. B. CAMPBELL AND N. FUSCHILLO, *Franklin Institute Laboratories.*—The investigation previously reported[1] for methane adsorbed on titanium dioxide (15 to 90°K) has been extended to coverages between one and four monolayers (BET). A comprehensive examination of the substrate particles by the methods of (a) BET adsorption, (b) x-ray diffraction, and (c) electron microscopy indicate that the particles are approximately spherical and have a mean diameter of 70 A by method (a) and 107 A by method (c). Diameters by methods (b) and (c) were in agreement to 7%, indicating single crystal particles. The disparity between the results of (a) and (c) indicates that the N_2-BET surface area is approximately half of that determined by direct observation. This may be explained by adsorption in surface defect regions of atomic dimensions[1,2] during the N_2-BET determination. The NMR line shapes below the λ-point temperature for CH_4 show a ΔH transition from 4.1 to 5.7 gauss (ΔH for solid bulk methane is 5.7 gauss) at 2.2 monolayers BET. This is also the threshold coverage for the first appearance of the λ-point discontinuity in the specific heat.[3] A narrow line component[1] ($\Delta H \leq 1.0$ gauss) is present at $T \geq 19$°K.

[1] N. Fuschillo and C. A. Renton, Bull. Am. Phys. Soc. Ser. II, **2**, 194 (1957).
[2] W. A. Steele and J. G. Aston, J. Chem. Phys. **23**, 1547 (1955).
[3] W. A. Steele, Proc. 5th Internatl. Conf. on Low-Temperature Physics, Madison, Wisconsin, 1957.

H13. Field Dependence of Proton Relaxation in Water Near Surfaces. R. J. S. BROWN, *California Research Corporation.*—A sample was prepared by crushing large, clear, natural quartz crystals in a bronze-jawed (nonferromagnetic) crusher, sieving with brass screens, and cleaning with hot oxidizing acids and distilled water. Sample in evacuated Pyrex container was baked 18 hr at 500°C. The sand was then saturated with oxygen-free distilled water and the sample sealed. An electron resonance spectrum on the dry quartz showed no sharp $g=2$ resonance; however, with high resolution and gain a faint peak over 1000 gauss wide was seen. Average grain diameter was 0.06 mm. T_1 and T_2 for the protons were measured by free precession in the earth's field. T_2 was shorter than T_1 at any relaxation field strength, H_r, and also showed memory of the strongest field experienced by the sample since a demagnetizing cycle, indicating a small magnetic retentivity, which, however, did not appreciably influence T_1. The surface contribution to relaxation rate (reciprocal time), $r_d = r$ (composite sample)-r(water), is nearly independent of field and temperature at fields from 75 to 1500 gauss, where $r_d = 0.24$ sec^{-1}. At 36 gauss, $r_d = 0.29$. At 100°, 51°, 20°, and 1.5°C r_d at 0.6 gauss is 0.66, 0.66, 0.60, and 0.47, respectively, with plots of r_d against log H_r approximately straight lines between 0.6 and 36 gauss. rms scatter of the points is about 0.025 sec^{-1} from the broken line described. Both electron and proton frequencies at the low fields correspond to correlation times longer than for bulk water.

THURSDAY MORNING AT 9:45

Terrace Room

(L. M. LEDERMAN presiding)

Strange Particles

HA1. K^- Meson Captures by Bound Neutrons. R. STEPHEN WHITE AND FRANCIS C. GILBERT, *University of California, Livermore.*—Experimental data is presented for K^- meson captures on bound neutrons. The model that was used to explain the captures on bound protons has been extended to apply to bound neutrons. In this model the average Σ hyperon nuclear potential is determined to be 35±10 Mev attractive and an estimated 75, 75, 60, and 55% of the Σ hyperons from the reactions $\Sigma^-\pi^+$, $\Sigma^-\pi^0$, $\Sigma^0\pi^-$, and $\Sigma^+\pi^-$, respectively, are trapped in bound-energy states. The Σ^+ or Σ^- hyperon charge exchange cross sections is estimated to be $11(+7,-6)$ millibarns per neutron or proton respectively in the Ag nucleus. The proton-to-neutron K^- capture ratio is found to be $4(+4,-2)$. The fraction of K^- captures on neutrons that lead to the reaction $\Lambda^0\pi^-$ is $0.00(+0.13,-0.00)$. The results indicate that most of the K^- mesons are captured in the interior of the nucleus. The data of this experiment are consistent with the reaction rates of $2:1:1\frac{1}{2}:0:\frac{1}{2}:\frac{1}{2}:0$ for $\Sigma^-\pi^+$, $\Sigma^+\pi^-$, $\Sigma^0\pi^0$, $\Lambda^0\pi^0$, $\Sigma^-\pi^0$, $\Sigma^0\pi^-$, and $\Lambda^0\pi^-$, respectively.

HA2. Detection of *K*-Meson Type *S* Events in Cosmic Radiation.* H. GURSKY, *Princeton University.*—A fast counter scheme was used in conjunction with a multiplate cloud chamber in an attempt to more efficiently detect K mesons produced in cosmic rays. Events were selected only if characterized by a delay coincidence between two scintillation counters; one of which was located within the cloud chamber, the other being directly above the chamber. The delay between the counter signals was set at 20 mμsec and the coincidence gate was of 100-mμsec duration. The signals were also dis-

played on an oscilloscope and photographed. The cloud chamber with sensitive volume 18×18×9 in. was operated at an altitude of 10 600 ft under 6 in. Pb. The chamber contained eight ½-in. brass plates representing about 110 kg of Cu stopping material. During 2500 hr of sensitive time, 20 000 cloud chamber pictures were taken. Seventy-five events were found which, on the basis of the ranges of the secondary and the mean life, are interpreted as stopping K^+ mesons. A lifetime analysis of these events is under way.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

HA3. Photoproduction of K Mesons from Hydrogen.* B. McDaniel, G. Cortellessa,† A. Silverman, and R. Wilson, *Cornell University.*—The angular distribution for the reaction $\gamma+p\rightarrow K^++\Lambda^0$ is being investigated by irradiating a liquid hydrogen target with the beam from the Cornell synchrotron. Measurements have been made of the K mesons produced by 1000-Mev photons at 155° and 90° in the center-of-mass system. Further measurements are in progress. It is hoped that a more complete distribution will provide information concerning the parity of the K meson. Magnetic momentum analysis has been used in conjunction with a counter telescope system to detect the K mesons. They are further identified by the detection in prompt coincidence (5×10^{-8} sec) of the secondaries emerging from the block of aluminum in which the K mesons are stopped. Results obtained thus far give a differential cross section of $(0.89\pm0.21)\times10^{-31}$ cm²/steradian[1] at 155° and $(1.83\pm0.4)\times10^{-31}$ cm²/steradian at 90°. Two hundred K particles were counted in the latter measurement and the stated estimate of error is in large part due to lack of knowledge of the effective aperture of the magnet. Measurements are in progress to diminish this uncertainty.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Istituto Superiore Di Sanita, Rome. Visiting Fulbright Fellow.
[1] Silverman, Wilson, and Woodward, Phys. Rev. (to be published).

HA4. Charge Exchange of Positive K Mesons.* M. N. Whitehead, R. W. Birge, W. B. Fowler, R. E. Lanou, and W. M. Powell, *University of California, Berkeley.*—The charge exchange scattering of positive K mesons is being studied in the 30-in. propane bubble chamber[1] with particular emphasis on the behavior of the neutral θ's produced in the process. A separated K beam[2] at the Bevatron with a momentum of 500 Mev/c and with a π^+/K^+ ratio of about 20/1 was used as a source. A small fraction of the 50 000 pictures that were taken has been roughly scanned to date and one θ_1^0 decay resulting from a charge exchange in the liquid has been found. The rough preliminary scan shows fewer θ_1^0-type decays than predicted on the basis of the emulsion data, assuming that 50% of charge-exchange events result in θ_1^0 decays.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Powell, Fowler, and Oswald, UCRL-8037 [Bull. Am. Phys. Soc. Ser. II, 3, 58 (1958), this issue].
[2] Designed by Donald H. Stork and John Mulvey.

HA5. Search for Charge Exchange of K Mesons.* R. E. Lanou, R. W. Birge, H. W. Courant,† and M. N. Whitehead, *University of California, Berkeley.*—A triggered multiple expansion cloud chamber has been used at the Bevatron to study the charge exchange of positive K mesons.[1] Events that triggered the chamber were selected from a momentum-analyzed K beam by a counter telescope containing scintillators and Cherenkov counters. The charge-exchange target was placed inside the cloud chamber with an anticoincidence counter behind it. An estimate based on emulsion data, including corrections for geometry, and the assumption that one-half the charge-exchanged K mesons decay by the θ_1^0 mode suggests that five θ_1^0, mesons should have been seen, whereas none has been found. The conclusion is drawn that the charge-exchange cross section is lower than expected.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
† Now at Yale University.
[1] Birge, Courant, Lanou, and Whitehead, Proc. Venice Conference (1957).

HA6. High-Energy K^+ Meson Scattering in Nuclear Emulsions.* G. T. Zorn and B. Sechi Zorn, *Brookhaven National Laboratory.*—The study of K^+ meson scattering in nuclear emulsion has been extended to K energies of 360 Mev. The emulsion stacks being examined were exposed in a "separated" K^+ beam realized at the Berkeley Bevatron. Based on 19.5 m of track length in the K energy interval 220–360 Mev, we observe a mean free path for inelastic scattering of 42±6 cm. This result taken with those previously reported at lower energies[1] confirms an increasing K-nucleon cross section above 170 Mev. The inelastic K scatters observed between 220 and 360 Mev are characterized by a large proportion of events in which no charged K particle emerges and which are considered as charge exchange events (C.E.); C.E./non C.E.~0.7. This is to be compared with that observed at lower energies: C.E./non C.E. $=0.23(+0.04,-0.03)$.[1] Rare events: An example of π^- meson production in a K^+-neutron interaction at 280 Mev has been observed. Two K^+-hydrogen scatterings have also been identified. More accurate values for the mean free path and further details on the nuclear interaction of K particles at these energies will be presented.

* Work carried out under the auspices of the U. S. Atomic Energy Commission.
[1] See B. Sechi Zorn and G. T. Zorn, Bull. Am. Phys. Soc. Ser. II, 2, 20 (1957) and Phys. Rev. (to be published).

HA7. Lifetime of the θ_2^0 Meson.* M. Bardon, W. Chinowsky, M. Fuchs, K. Lande, and L. Lederman, *Columbia University and Brookhaven National Laboratory,* and J. Tinlot, *University of Rochester and Brookhaven National Laboratory.*—Long-lived neutral V events have been observed in the Columbia 36-in. cloud chamber exposed to radiation from a target at a distance of 18.0 ft when the target is bombarded with 3-Bev protons from the Brookhaven Cosmotron. A new exposure has recently been made, in which the target-to-chamber distance has been increased to 71.5 ft. This corresponds to a mean flight time of 1.2×10^{-7} sec for θ_2^0 particles as contrasted with 3×10^{-8} sec in the earlier exposure. The angle made by the line of flight of the neutral beam with the incident proton direction was held to 68±1° in both exposures. Comparison of the two yields (140 events in the old run, 28 events in the new run) provides a measure of the mean life of the θ_2^0. To determine the relative flux at the target, the number of events is normalized to (1) incident proton beam intensity, (2) number of neutron-induced stars in the cloud chamber gas, and (3) spectrum of energetic protons ejected from the thin window by neutrons in the beam. All three methods lead to agreement and result in a lifetime estimate of $\tau(\theta_2^0)=7.8(+4.9,-3.2)\times10^{-8}$ sec. Scanning efficiency and production spectrum contribute chiefly to the errors which are in the nature of limits.

* This work is supported by the U. S. Atomic Energy Commission.

HA8. Strange Particle Production in π^+-P Collisions at 950 and 1300 Mev.* F. Eisler, R. Plano, N. Samios, and J. Steinberger, *Columbia University,* and A. Prodell and M. Schwartz, *Brookhaven National Laboratory.*—Results on the angular distribution and total cross sections of the reactions,

$$\pi^-+P\rightarrow\Lambda^0+\theta^0,$$
$$\pi^-+P\rightarrow\Sigma^0+\theta^0,$$
$$\pi^-+P\rightarrow\Sigma^-+\theta^+,$$

will be presented, on the basis of approximately 300 events obtained in the hydrogen and propane bubble chamber.

* This work is supported by the U. S. Atomic Energy Commission and the Office of Naval Research.

HA9. Σ^+ Production by θ^0 Mesons.* M. CRESTI, F. S. CRAWFORD, JR., M. L. GOOD, K. GOTTSTEIN, E. M. LYMAN, F. T. SOLMITZ, M. L. STEVENSON, AND H. K. TICHO, *University of California, Berkeley.*—Two θ^0 mesons have been observed to interact with protons in a liquid hydrogen bubble chamber. The interactions yield, in each case, a charged positive particle which decays after $\sim 0.3\times10^{-10}$ sec and $\sim 0.2\times10^{-10}$ sec, respectively. The dynamics of both events are consistent with either a K^+ or a Σ^+ production, but the fast decay in both instances is strongly in favor of the Σ^+ hypothesis. The events show, then, the interaction of a θ^0 meson in its state of negative strangeness. The cross section estimated from these two events is roughly geometrical.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

HA10. Associated Production Cross Sections at 1.1 Bev/c.* F. S. CRAWFORD, JR., M. CRESTI, M. L. GOOD, K. GOTTSTEIN, E. M. LYMAN, F. T. SOLMITZ, M. L. STEVENSON, AND H. K. TICHO, *University of California, Berkeley.*—Table I summarizes the total cross sections (in mb) and the differential cross sections (in μb/sterad) for the reactions $\pi^-+p\rightarrow\Lambda+K^0$, $\pi^-+p\rightarrow\Sigma^0+K^0$, and $\pi^-+p\rightarrow\Sigma^-+K^+$. The incident pion momentum is 1.1 Bev/c; θ is the center-of-mass angle of the hyperon. These angular distributions show more isotropy than

TABLE I.

Reaction products	Number of events	σ_{tot} (mb)	$\frac{d\sigma}{d\Omega}=A+B\cos\theta+C\cos^2\theta$ (μb/sterad) A	B	C
$\Lambda+K^0$	76	0.49±0.11	32±7	−44±8	20±16
Σ^0+K^0	25	0.19±0.04	1±4	3±5	14±11
Σ^-+K^+	121	0.22±0.03	12±2	5±3	15±6

the data of Glaser *et al.* at 1.2 Bev/c. The value of the Λ total cross section lends support to the already reported trend[1] that the Λ total cross section decreases with increasing momentum. Additional data at 1.1 and 1.2 Bev/c will be presented.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Data of the Bologna, Brookhaven, and Michigan Groups, summarized at the Seventh Annual Rochester Conference on High-Energy Physics, 1957.

HA11. Photostar Production by 500- to 1100-Mev Bremsstrahlung.* CHARLES E. ROOS, *University of California, Riverside,* AND VINCENT Z. PETERSON, *California Institute of Technology.*—Electron sensitive nuclear emulsions were exposed at normal incidence to the bremsstrahlung photons produced at a series of different synchrotron energies. All stars in the exposed area were counted and corrected for measured scan efficiency and pre-exposure background. In conjunction with earlier experiments between 200 and 500 Mev[1] preliminary work indicates that the photostar cross section per photon remains approximately constant between 300 and 1100 Mev. This cross section is obtained by the photon difference method and is approximately 30 millibarns per silver nucleus. It may be possible to explain photostar production in terms of the reabsorption of real pions. The importance of multiple meson processes is indicated by the continued high level of the photostar cross section well past the resonance for free nucleon single photomeson production. The very short mean free path of pions in nuclear matter ($\lambda\approx1.2\times10^{-13}$ cm) which was required to fit the data below 500 Mev is in rough agreement with the values calculated from the optical model.[2]

* This work was supported in part by the U. S. Atomic Energy Commission and the Research Corporation.

[1] V. Z. Peterson and C. E. Roos, Phys. Rev. 105, 1620 (1957).
[2] Frank, Gammel, and Watson, Phys. Rev. 101, 893 (1956).

HA12. Decay Modes and Lifetime of Σ Hyperons. S. C. FREDEN, F. C. GILBERT, AND R. S. WHITE, *University of California, Livermore.*—A systematic study is being made to identify the lepton decay modes of the Σ hyperons $\Sigma^\pm\rightarrow\mu^\pm+n+\nu$ and $\Sigma^\pm\rightarrow e^\pm+n+\nu$. From the K^- capture stars in nuclear emulsion stacks exposed to K^- meson beams at the Berkeley Bevatron, 42 decays of Σ hyperons into light charged particles have been analyzed. Eighteen of these have been identified as Σ^+ hyperon decays at rest, 8 as Σ^+ decays in flight, 6 as Σ^- decays in flight, and 10 as $\Sigma^\pm$ decays in flight. To date, 14 π mesons have been identified by their characteristic endings or interactions in flight. No μ mesons have been identified. The remaining 28 decay prongs did not end in the stack and were either π or μ mesons as identified by Δg vs ΔR and multiple scattering measurements. No electrons have been identified. In order to avoid decays at rest the lifetime for decays in flight was determined using a cutoff of 5×10^{-11} sec, corresponding to the last 2.2 mm of hyperon path. The mean lifetime for Σ hyperon decay in flight into light particles, obtained from 15 events, is $4.8(+2.5,-1.0)\times10^{-11}$ sec. This low value is in agreement with those obtained by the Wisconsin and N.R.L. groups.

HA13. Search for a Particle of Mass 500 m_e.* A. HENDEL, P. PIROUE, AND GEORGE T. REYNOLDS, *Princeton University.*—Following previous work done in this Laboratory[1] we have investigated the existence of cosmic ray particles of mass between that of the light mesons and the proton. Evidence for a particle of mass 550 m_e was also reported by a Russian group.[2] The Princeton double cloud chamber was used at 10 600-ft altitude to obtain a mass spectrum of cosmic ray particles. No production layer was used. The upper cloud chamber was operated in a magnetic field of 5500 gauss and the lower chamber contained seven copper plates of ½ in. thickness each. The particles were required to traverse a Čerenkov counter to eliminate some of the μ mesons. The results of these measurements will be discussed.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] G. K. Lindeberg, thesis, Princeton University, 1957.
[2] Alikhanyan *et al.* Zhur. Eksptl. i Teoret. Fiz. V, 31 (1955).

THURSDAY MORNING AT 9:45

Panel Room

(W. W. BUECHNER presiding)

Nuclear Reactions I

J1. A Search for H^5.* G. W. TAUTFEST, *Purdue University.*—In a recent paper,[1] Blanchard and Winter have suggested that H^5 may be particle stable. If true, H^5 is a delayed neutron emitter with a half-life $\sim$10/msec. We have searched for delayed neutrons from a 14.2 g/cm² Li^7 target irradiated with the 320-Mev bremsstrahlung beam from the Purdue Univer-

sity synchrotron. The target is surrounded with an array of BF_3 counters in a moderator. Neutrons are counted in nine delay channels between beam pulses. With a carbon moderator delayed neutrons are observed, with the target in position, with a half-life of 0.17 sec. This signal is attributed to the $C^{12}(n,n'3p)Li^9$ reaction taking place in the moderator. With a water moderator, no signal is observed with a half-life longer than the moderation time. If, as has been pointed out by R. W. King,[3] 10 msec represents a lower limit to the half-life, we can place a lower limit of 10^{-32} Mev/cm^2 for the $Li^7(\gamma,2p)H^5$ cross section integrated to 320 Mev. It is suggested that H^5 does not exist.

* Supported in part by the U. S. Atomic Energy Commission.
[1] C. H. Blanchard and R. G. Winter, Phys. Rev. 107, 774 (1957).
[2] R. W. King (private communication).

J2. $He^3(\alpha,\gamma)Be^7$ Reaction. H. D. Holmgren and R. L. Johnston, *U. S. Naval Research Laboratory.*—The capture cross sections for the $He^3(\alpha,\gamma)Be^7$ reaction have been measured at 5 bombarding energies extending from 0.47 to 1.32 Mev. A 5-cm long gas target chamber was filled with 94% enriched He^3 gas to a pressure of 75 mm. The gamma ray detector was a 5 in. diameter×3-in. NaI crystal with a 1-in. diameter hole in the center in which the gas target cell was placed. In order to determine the absolute cross sections, the yield of gamma rays at 1.32 Mev was measured with a 3×3-in. NaI crystal whose efficiency has been calculated for various geometries. In the energy range investigated, the total capture cross section may be represented by $\sigma = 2.8E^{2.25}(\mu b)$. At a bombarding energy of 1.32 Mev about 50% of the reactions proceed by cascading through the 0.430 Mev level of Be^7.

J3. (p,n) Reactions in Light Nuclei. I. R. L. Macklin and J. H. Gibbons.—A large neutron detector, employing a 5-ft diameter graphite sphere and BF_3 counters, has been constructed with essentially flat efficiency from 1 kev to 2 Mev. Measurements have been made of total absolute (p,n) cross sections from threshold to 5 Mev for thin targets of Be^9, B^{10}, B^{11}, and C^{13}.

J4. (p,n) Reactions in Light Nuclei. II. J. H. Gibbons and R. L. Macklin.—Using the apparatus described in the preceding abstract, total absolute cross sections have been measured from threshold to 5 Mev for the following reactions: (1) $D(p,p')pn$, (2) $T(p,n)He^3$, and (3) $Li^7(p,n)Be^7$. The yield near threshold in reaction (1) indicates the importance of Coulomb effects. From reaction (2) the $He^3(n,p)T$ reaction cross section has been calculated by reciprocity. Theoretical fits to reactions (2) and (3) will be presented and discussed.

J5. Lifetime of the First Excited State of B″.* V. K. Rasmussen, F. R. Metzger, and C. P. Swann, *Bartol Research Foundation.*—A thick B_4C target was bombarded by 3000-Mev protons to give a strong source of Doppler-broadened 2.14 Mev γ rays from the first excited state of B″. The scattering of these γ rays by B_4C and $LiNO_3$ was measured, the difference being attributed to nuclear resonance fluorescence in B″. Assuming spin $\frac{1}{2}$ for the excited state, its mean lifetime is found to be 4.8×10^{-15} sec. The self-absorption of the resonance radiation in B_4C was also measured, and the resulting lifetime found to be 4.3×10^{-15} sec. From both measurements, $\tau = (4.6\pm0.6)\times10^{-15}$ sec. In the $B''(p,p')$ reaction, the recoiling B″* nuclei are confined, in the laboratory system, to a forward cone (half-angle of 27.5° for $E_p = 3$ Mev). Because of the Doppler effect, photons will have the resonant energy, $E_{level}[1+E_{level}/(2Mc^2)]$, only if emitted at ~88° to the B″* velocity. Thus resonance fluorescence will be observed only if the scatterer is within a restricted zone around 88° to the proton beam. We have verified this, and have also shown that for 3-Mev protons on a thick target the inelastic protons are, on the average, approximately isotropic.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

J6. Phase Shift Analysis of $N^{14}(p,p)N^{14}$. A. J. Ferguson, *Chalk River Laboratories.*—A phase shift analysis has been made of a set of angular distributions[1] for the elastic scattering of protons by nitrogen in the energy range 1.0 Mev to 3.0 Mev. Three independent phase shifts have been assumed; two S-wave phase shifts for the $\frac{1}{2}+$ and $\frac{3}{2}+$ states and a single phase shift of hard sphere type for the P waves. An S-wave resonance will be accounted for by this procedure but not one involving higher waves. Reasonably good fits have been obtained for the nonresonant scattering below 2.3 Mev and for the region of the S-wave resonance at 1.557 Mev indicating that the gross features of the scattering are adequately represented. In some details the fits are unsatisfactory, indicating more complicated behavior for the P waves. From 2.3 Mev to 3.0 Mev the fits are poor. The results indicate a broad $\frac{1}{2}+$ resonance at 2.3 Mev with a width of 0.5 Mev. This is probably the same resonance reported by Duncan and Perry.[2]

[1] Ferguson, Clarke, and Gove (to be published).
[2] D. B. Duncan and J. E. Perry, Phys. Rev. 82, 809 (1957).

J7. Elastic Scattering of Alpha Particles by N^{15}.* H. Smotrich, K. W. Jones, L. C. McDermott, and R. E. Benenson, *Columbia University.*—The absolute differential cross section for the elastic scattering of alpha particles by N^{15} has been measured from 1.7 Mev to 5.4 Mev at center-of-mass angles of 90, 125, 141, and 168 degrees, The N^{15} target gas was recirculated through a differentially pumped gas scattering chamber. A thin CsI scintillation counter was used to detect the scattered alpha particles. Gas purity was measured frequently with a mass spectrometer and was better than 90% throughout the experiment. Over twenty resonances were observed, corresponding to excited states of F^{19} above 5.4-Mev excitation energy. In general, levels with excitations up to approximately 7 Mev are narrow (~10 kev); above this energy the levels become much broader.

* This work was partially supported by the U. S. Atomic Energy Commission.

J8. Angular Distributions of Deuterons from the Reactions $F^{19}(p,d)F^{18}$ and $Mg^{25}(p,d)Mg^{24}$ Using 18-Mev Protons.* E. F. Bennett, *Princeton University.*†—A two-dimensional pulse-height analyzer used to record coincidences from a thin proportional counter measuring dE/dx and an NaI crystal measuring E permitted deuterons from proton induced reactions in F^{19} and Mg^{25} to be resolved from an inelastic proton background considerably more intense. Deuterons leaving F^{18} in 6 states of excitation were observed and angular distributions on these groups were carried out. In addition to the levels at 0.94 and 1.05 Mev which are probably 3^+ and 0^+, even parity levels were found at 1.7 and 4.1 Mev and these are believed to be 0^+ and 2^+, respectively. An odd parity level of spin 0,1,2 was found at 3.4 Mev. Three deuteron groups were observed in the reaction $Mg^{25}(p,d)Mg^{24}$ leaving Mg^{24} in excitations of 0, 1.4, and 4.1 Mev. All three groups indicated $l=2$ pick-up only with reduced neutron widths in the ratio 1:2.2:.65. Mention will be made of the agreement between level width ratios and theory where calculations have been done.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
† Now at Argonne National Laboratory.

J9. Pickup Reactions in the d Shell. J. S. Blair, *Princeton University.**—Branching ratios for deuteron stripping into specific final states have been presented by Satchler[1] for the

case where a nucleon with definite j is strongly coupled to a deformed core. Modifications of these results when Nilsson wave functions are employed have been given by Sawicki.[2] As a test of the deformed core model, the analogous branching ratios to different states of a rotational band are here computed for some typical (p,d) reactions in the d shell. For $Mg^{25}(p,d)Mg^{24}$, a relatively unambiguous prediction can be made that the final population of the $L=0,2,4$ states is in the ratio 1:1.79:0.21. With Na^{23} and Ne^{21} targets ($J=\frac{3}{2}$), an $L=0$ final state can be populated only if there is mixing of $d_{\frac{3}{2}}$ with $d_{\frac{5}{2}}$ orbitals. Branching ratios are also estimated for (p,α) reactions.

* Supported in part by the U. S. Atomic Energy Commission and The Higgins Scientific Trust Fund.
[1] G. R. Satchler, Phys. Rev. **97**, 1416 (1955).
[2] J. Sawicki (to be published).

J10. Alpha-Particle Bombardment of N^{14}.* J. R. RISSER, P. D. MILLER, AND EDWIN KASHY, *The Rice Institute.*—Measurements of the differential cross section for elastic scattering of alpha particles from N^{14} and for the ground-state protons from the reaction $N^{14}(\alpha,p)O^{17}$ have been carried out with a differentially pumped gas scattering chamber using the He^{4+} beam from the Rice Institute Van de Graaff accelerator. Excitation curves for the protons and scattered alpha particles have been taken in the laboratory energy range from 2.5 to 5 Mev at a number of c. m. angles, and proton angular distributions at a number of energies in this range. Agreement is excellent with similar measurements made by Heydenburg and Temmer[1] in the energy range up to 3.5 Mev. In addition strong resonances have been observed at 4.00, 4.05, 4.11, 4.28, 4.50, and 4.55 Mev, corresponding to levels in F^{18*} at 7.52, 7.56, 7.61, 7.74, 7.91, and 7.95 Mev. The approximate c. m. widths of these resonances are respectively 35, 60, 40, 120, 30, and 70 kev.

* Supported in part by the U. S. Atomic Energy Commission.
[1] N. P. Heydenburg and C. M. Temmer, Phys. Rev. **92**, 89 (1953).

J11. Levels of F^{18}. I. $O^{16}(He^3,p\gamma)F^{18}$. J. A. KUEHNER, E. ALMQVIST, AND D. A. BROMLEY, *Chalk River Laboratories.*—Seven excited states of F^{18} at excitations less than 3.5 Mev have been observed in the $O^{16}(He^3,p\gamma)F^{18}$ reaction using 2.4-3.1 Mev He^3 ions. Five of these states, at excitations of 0.94, 1.74, 2.09, 2.54, and 3.3 Mev, have previously been observed in the $Ne^{20}(d,\alpha)F^{18}$ reaction[1] and very probably have $T=0$. Additional levels, at 1.08 and 3.07 Mev, not observed in the d,α reaction, probably have $T=1$. p,γ coincidence techniques have been used to measure branching ratios for the de-excitation of all states except that at 3.3 Mev. In all cases transitions to the 1+ ground state have been observed, while transitions to the 0.94-Mev state have been seen from the states at 2.09, 2.54, and 3.07 Mev. The 1.08-Mev state is fed by the de-excitation of states at 1.74, 2.09, and 3.07 Mev. Angular distribution and p,γ angular correlation measurements show isotropy for the 1.08 Mev radiation suggesting a spin zero assignment. Each of the remaining states shows at least one transition whose angular distribution is not isotropic, excluding the possibility of spin zero.

[1] R. Middleton and C. T. Tai, Proc. Phys. Soc. (London) **A64**, 801 (1951).

J12. Levels of F^{18}. II. $N^{14}(\alpha,\gamma)F^{18}$. E. ALMQVIST, D. A. BROMLEY, AND J. A. KUEHNER, *Chalk River Laboratories.*—The 5.60-Mev level in F^{18} was excited by the bombardment of TaN targets with 1.53 Mev α particles. Gamma rays of energies 5.60, 4.52, 3.07, 2.53, 2.12, 1.08, and 0.94 Mev were observed and studied using coincidence techniques. The observations together with the level properties reported in the previous paper yield the following branches from the capturing state: (a) 5.60→0(5%), (b) 5.60→1.08(28%), (c) 5.60→3.07(67%). These observations favor the assignment $1-,T=0$ to the 5.60-Mev level; (a) is then an isotopic spin forbidden ($\Delta T=0$) El transition while (b) and (c) are allowed ($\Delta T=1$) El transitions to the two lowest $T=1$ levels in F^{18} with expected properties 0+(1.08 Mev) and 2+(3.07 Mev). The observed angular distributions are consistent with these assignments and are of the forms: $P_0-0.19(\pm0.15)P_2$ for 5.60-Mev radiation, $P_0+0.47P_2$ for 4.53-Mev radiation and nearly isotropic for the 2.53-Mev radiation. The $2+,T=1$ state at 3.07 Mev shows a 20% ground-state branch and an 80% branch via a 2.12-Mev transition to the 0.94-Mev level.

[1] P. C. Price, Proc. Phys. Soc. (London) **68A**, 553 (1955).

J13. Levels of F^{18}. III. D. A. BROMLEY, J. A. KUEHNER, AND E. ALMQVIST, *Chalk River Laboratories.*—Delayed coincidence measurements on the gamma de-excitation of the 0.94-Mev state in F^{18} have established that $\tau\leq5\times10^{-9}$ sec. Together with the angular distributions reported in I this implies that $1\leq J\leq3$ for this state. Triple angular correlation measurements have been carried out on the $N^{14}(\alpha,\gamma\gamma)F^{18}$ reaction involving the F^{18} states at 5.60, 3.07, and 0.94 Mev. These correlations show weak anisotropies but do not permit an unambiguous spin assignment to the 0.94-Mev state. Further triple correlation measurements, using other geometries, are in progress in an attempt to remove this ambiguity. The available information on the F^{18} levels will be compared with the detailed intermediate-coupling shell-model calculations of Elliott and Flowers.[1] Agreement is much less satisfactory than in the case of F^{19} and may suggest revision of the potential used in the calculations.

[1] J. P. Elliott and B. H. Flowers, Proc. Roy. Soc. (London) **229A**, 536 (1955).

THURSDAY MORNING AT 9:45

Grand Ballroom

(H. D. Smyth presiding)

Symposium on High-Temperature Plasma

JA1. Title to be announced. JAMES TUCK, *Los Alamos Scientific Laboratory.* (30 min.)

JA2. Nonthermonuclear Neutrons from Linear Deuterium Pinches. S. A. COLGATE, *University of California, Livermore.* (30 min.)

JA3. Validity of Hydromagnetic Plasma Models. MARTIN KRUSKAL, *Princeton University.* (30 min.)

JA4. Basic Problems in Low-Pressure Plasmas. S. C. BROWN, *MIT.* (30 min.)

THURSDAY MORNING AT 9:45

Empire Suite

(A. G. SHENSTONE presiding)

Spectroscopy

K1. Microwave Spectroscopy on ClCN Using Maser Techniques.* P. THADDEUS, A. JAVAN, AND A. OKAYA, *Columbia Radiation Laboratory, Columbia University.*—The rotational transition $J=2\leftarrow1$ has been observed for the moledule ClCN, using the maser techniques developed for ammonia. Since the population distribution of the molecules over the relevant quantum states is less favorable than for ammonia, a considerably more sensitive microwave detection system has been developed. The electric quadrupole coupling of the Cl and N produces a hyperfine structure for this transition; the observed line widths are of the order of 1.5 kc/sec. The detection system consists of a superheterodyne, phase sensitive amplifier with a band width of about one cycle. The power source is a stabilized klystron, swept at a slow rate over a range of about 10 kc/sec. A well stabilized klystron is essential for this type of spectroscopy. The klystron used has a long term stability sufficient for use with much narrower band widths, and a short term stability of better than 200 cycles/sec. In order to obviate the difficulties caused by the broadness of a conventional frequency standard marker, the frequencies of the observed lines are being measured using the maser oscillation of the ammonia 3,3 inversion line as a standard. The measurements in progress will permit the calculation of the $I\cdot J$ coupling constant for the first time.

* Work supported jointly by the Signal Corps, the Office of Naval Research, and the Air Force Office of Scientific Research.

K2. Neutron Investigation of Optical Vibration Levels in Zirconium Hydride.* WILLIAM L. WHITTEMORE,† *General Dynamics Corporation.*—A recent investigation of zirconium hydride[1] has revealed the existence of a sharp "optical" frequency corresponding approximately to vibrations of the individual hydrogen atoms in an isotropic harmonic well. The present report results from a further experimental investigation of this oscillator made by studying its effect on the energy dependence of the total neutron cross section of zirconium hydride. Fermi[2] and others have derived expressions for the energy dependence of the neutron cross section for a system similar to that of zirconium hydride. These expressions will be compared with the experimental results.

* Experimental observations made at the Brookhaven National Laboratory.
† Guest Scientist, Brookhaven National Laboratory.
[1] Phys. Rev. (to be published).
[2] Ricerca sci. VII, 2 (1936).

K3. Collision-Induced Microwave Absorption in Nonpolar Gases. A. A. NARYOTT, P. F. WACKER, AND G. BIRNBAUM,* *National Bureau of Standards.*—Absorption of microwave radiation by the nonpolar gases, carbon dioxide and ethylene, has been detected. Measurements made by sensitive resonant cavity techniques at frequencies near 9 and 23 kmc/sec and pressures up to 60 atmos yielded dielectric loss tangentswhich were proportional to frequency, very nearly proportional to density squared, and as high as 33.3×10^{-6}. Assuming the losses to be due to dipole moments induced by the quadrupole moments of neighboring molecules, a semiquantitative explanation of the results has been obtained. Using the theory of Buckingham and Pople, and existing data for the quadrupole moment, polarizability, and gas density, our CO_2 data indicated an effective relaxation time of roughly 3×10^{-13} sec, independent of density. Both this time, which is comparable to the duration of a collision, and the experimental pressure dependence indicate that the loss is not due to the presence of a polar dimer. In addition, no other plausible explanation which has been conceived can account for the data. Further, computations for CO_2, C_2H_4, H_2, N_2, and C_2H_6 are consistent with the experimental ratio of the effects for the first two gases and with the failure to observe the effect in the remaining three gases.

* Now at Hughes Research Laboratories.

K4. Green Bands of the XeO Spectrum.* C. DEWEY COOPER AND GROVER C. COBB, *University of Georgia.*—Spectra in the green region which are associated with the 5577A oxygen line have been attributed to excited XeO molecules.[1,2] We have produced similar spectra with a xenon and oxygen mixture at a pressure of one atmosphere in an ozonizer-type discharge with 4-Mc excitation. Low dispersion spectra confirm and extend the vibrational analysis of Herman.[1] The high intensity of the source has permitted us to obtain spectra with a plate factor of 1 A/mm. The rotational lines are resolved but are not sharp. They split into four components for higher J values. We assume that the transition occurs between the molecular states $Xe(^1S_0)O(^1S_0)$ and $Xe(^1S_0)O(^1D_2)$. For such a transition Hunds case b or c coupling will not permit the type of line splitting reported above. The only coupling for the assumed molecular states which can account for the four line components is case d with quadrupole radiation. A weak continuum between 8750 and 6500 A is attributed to the $Xe(^1S_0)O(^1D_2)-Xe(^1S_0)O(^3P)$ transition.

* Supported by Air Force Cambridge Research Center.
[1] L. Herman and R. Herman, J. phys. radium 11, 69 (1950).
[2] Kenty, Aicher, Noel, Poritsky, and Paolino, Phys. Rev. 69, 36 (1946).

K5. Spectra Emitted from Solid Nitrogen at 4.2°K during and after Electron Bombardment.* E. HÖRL, *National Bureau of Standards* (introduced by L. Marton).—By varying intensity and energy of the bombarding electron beam (4.5 kv − 36 kv) and by using nitrogen of different kinds of purity a variety of emission spectra from solid nitrogen condensed at 4.2°K were observed. The main feature of these spectra is a green line at 5230 A believed to be the result of atomic nitrogen and two band systems in the blue and ultraviolet part of the spectrum due to electronic excited nitrogen molecules. The one system is the Vegard-Kaplan bands, the other one is probably $^5\Sigma-{}^5\Sigma$ transitions.[1] The observed spectra are similar to those first observed by L. Vegard[2] and by J. C. McLennan and G. M. Shrum.[3] There is also similarity to the spectra of products of an electric discharge in flowing nitrogen frozen out at 4.2°K.[4]

* This research was performed under the NBS Free Radicals Program supported by the Department of the Army.
[1] C. M. Herzfeld and H. P. Broida, Phys. Rev. 101, 606 (1956).
[2] L. Vegard, Nature 113, 716 (1924).
[3] J. C. McLennan and G. M. Shrum, Proc. Roy. Soc. (London) A106, 138 (1924).
[4] A. M. Bass and H. P. Broida, Phys. Rev. 101, 1740 (1956).

K6. Microwave Spectrum and Structure of ReO_3F.* J. F. LOTSPEICH AND A. JAVAN, *Columbia University,* AND A. ENGELBRECHT, *Temple University.*—Preliminary results on the spectrum of perrhenyl fluoride have been reported previously.

Subsequent detailed measurements, taking into account the small isotopic shift and difference in quadrupole hfs splittings associated with the two Re isotopes, have yielded the following more reliable values for quadrupole coupling, rotation-vibration, and l-type doubling constants: $eqQ(Re^{187}) = (-48.4 \pm 1.3)$ Mc, $\alpha_3 = (+12.30 \pm 0.06)$ Mc, $\alpha_5 = (-10.91 \pm 0.06)$ Mc, $q_{l3} = (16.31 \pm 0.25)$ Mc, $\alpha_4 = (+2.52 \pm 0.06)$ Mc, $q_{l4} = (5.00 \pm 0.24)$ Mc. Strong dependence of quadrupole coupling on molecular vibration was observed, the values of $eqQ(Re^{187})$ being -27, -35, and -58 Mc, respectively, in the singly-excited vibrational states ν_3, ν_5, and ν_6. The very small amount of unbalanced p electron along the molecular axis is shown to explain the pronounced variations in q at the Re nucleus during vibration. The asymmetric-top spectrum due to the O^{18}-substituted species $ReO_2{}^{16}O^{18}F$ yielded values for the three bond parameters: $Re-O = (1.692 \pm 0.003)$ A, $Re-F = (1.859 \pm 0.008)$ A, $F-Re-O = 109° 31' \pm 16'$. A value of 1.761 A for the Re–O bond distance in ReO_3Cl reported by Amble *et al.* was found to be in error; the corrected figure 1.702 A is here submitted, in close agreement with that of the same bond in ReO_3F. Comparison of the structure and quadrupole coupling of ReO_3F with those of ReO_3Cl and MnO_3F provides information concerning the valence electron bond configurations of heptavalent rhenium and manganese.

* Work supported by the U. S. Atomic Energy Commission.

K7. Calculations of Energy Levels and g Values for RuI, TaII, and ReI. R. E. TREES, *National Bureau of Standards.*—Calculations of energy levels and g-values were made for low, even configurations of third and fourth long period spectra. Spin-orbit and electrostatic parameters were determined by least-squares. Similar parameters were adjusted separately in different configurations except for G_2H_2 and α. The 59 levels known in the configurations $4d^3+4d^25s+4d^35s^2$ of RuI were fitted with a mean deviation of ± 53 K by using 15 parameters. The parameters B and C show linear dependence on the configuration to within 10%. Previously, 37 levels of the configurations $5d^3+5d^26s+5d6s^2$ of TaII were fitted with a mean deviation of ± 371 K by using 8 parameters.[1] A level at 18 500 was rejected but it is now certain that the level at 16 424 is unreal instead. This reduces the mean deviation to ± 278 K, without readjustment of the 8 parameters. A mean deviation of ± 77 K was obtained with 15 parameters, but eight newly observed levels were not included. The 51 levels known in the $5d^36s^2+5d^46s$ configurations of ReI were fitted with a mean deviation of ± 325 K by using 11 parameters. The parameter α was 67 ± 13.

[1] Trees, Cahill, and Rabinowitz, J. Research Natl. Bur. Standards **55**, 335 (1955).

K8. Effect of Atomic Interactions on the Spectra of Gaseous Mixtures. O. JEFIMENKO, *West Virginia University* (introduced by Charles D. Thomas).—As a result of atomic and molecular interactions in the mixtures of gases or vapors, new bands and diffuse lines appear in the spectra of such mixtures. These bands and lines are not present in the spectra of the components of the mixture taken separately and constitute spectral forms characterizing a particular mixture. They appear as interaction satellites near certain atomic lines with intensities varying from a few tenths to a few thousandths of the intensity of the parent lines. The regularities in the occurrence of these satellites as observed both in emission and absorption suggest new possibilities for the spectrochemical analysis as well as for the interpretation of stellar spectra and the sun spectrum, in particular. The existence of interaction spectra indicates the need for revision of the theories of pressura broadening and the shape of atomic lines.

K9. X-Ray Mass Absorption Coefficients. ALAN J. BEARDEN, *The Johns Hopkins University.*—Major discrepancies in the published values of the ratio of K shell to $(L+M)$ shell photoelectric absorption have led to considerable mistrust in experimental photoelectric cross sections. New measurements of the mass absorption coefficients for spectroscopically pure aluminum, copper, tin, and gold at x-ray energies of 8, 10, 12.5, 15, 20, 25, 30, 35, and 40 kv have been made by the use of a double quartz crystal x-ray monochromator and the continuous radiation from a tungsten target. Exceptionally high resolving power has been obtained by the use of 1011 and 2023 planes in natural quartz. A small NaI(Th) scintillator, which absorbed ~100% of the transmitted radiation was used as the x-ray detector. Resulting measurements are accurate to within one percent. These values will be presented in tabular form and compared with previous measurements and also the calculated values of Grodstein.[1]

[1] Gladys White Grodstein, Natl. Bur. Standards Circ. No. 583.

K10. Experimental L-Shell Fluorescence Yields. N. H. LAZAR AND W. S. LYON, *Oak Ridge National Laboratory.*—The "average" L-shell fluorescence yield, w_L, has been measured for Tb, Yb, Hf, Hg, Tl, and Pb using radioactive sources. The technique, based on the fact that each K_α x-ray emitted labels a vacancy in the L-shell, involved the determination of the coincidence rates, $P(L)$, between K x-rays (detected with a 3×3-in. NaI(Tl) crystal) and L x-rays (detected in a 1½×½-in. NaI(Tl) crystal in a beryllium can). By use of the relationship,

$$P(L) = C(K)K_\alpha/Kw_L\epsilon_p\Omega A,$$

where $C(K)$ is the counting rate of K x-rays observed with the 3×3-in. crystal, ϵ_p is the efficiency and Ω the solid angle for the thin NaI(Tl) crystal, A the absorption of beryllium or other matter between the source and the thin detector, and K_α/K is the fraction of K x-rays emitted per K x-ray transition, taken from x-ray data.[1] The results are in agreement with the early work of H. Lay.[2]

[1] A. H. Compton and S. K. Allison, *X-rays in Theory and Experiment* (D. Van Nostrand Company, Inc., New York, 1935), second edition, p. 640.
[2] H. Lay, Z. Physik **91**, 533 (1934).

K11. X-Ray Emission Spectrum of Lithium.* JOSEPH CALLAWAY, *University of Miami.*—In an attempt to explain the observed soft x-ray emission spectrum of lithium, the energy dependence of the transition probability between the conduction band and the $1S$ level has been calculated. The calculation was based on cellular method wave functions obtained using the Seitz semiempirical potential by Silverman and Kohn.[1] The wave function of an electron in the band was found to third order in the wave vector $\mathbf{K}$. The wave function of a $1S$ electron was also derived for this potential. The emission intensity is proportional to the product $\nu^3 |M_{iS,\mathbf{K}}|^2 N(E)$ where ν is the frequency of the x ray, $M_{iS,\mathbf{K}}$ is the matrix element for the transition, and $N(E)$ is the density of states. The emission intensity was found to have the form const. $\times E^{\frac{1}{2}}(1+1.17\,E)$. This result is not in agreement with experiment where a gradual drop in intensity is observed before the Fermi surface is reached.

* Supported in part by the Office of Naval Research.
[1] W. Kohn (private communication).

THURSDAY MORNING AT 9:30

Governor Clinton

(J. A. BURTON presiding)

Semiconductors III: Radiation Damage

KA1. Effective Mass of Electrons in Gallium Arsenide.* L. C. BARCUS, A. PERLMUTTER, AND J. CALLAWAY, *University of Miami.*—The index of refraction of *n*-type gallium arsenide has been measured in the infrared between 0.78 and 15 microns using a technique similar to that of Simon[1] which will be described. The reflectivity shows a decrease beginning at about 8 μ which can be attributed to the free electrons ($n = 6.9\times10^{17}$ cm^{-3}). The extinction coefficient is less than 0.1 throughout this region. Measurements at longer wavelengths are in progress. The effective mass of the electrons was determined from the computed dielectric susceptibility according to the procedure of Spitzer and Fan.[2] A value $m^*/m_0 = 0.04\pm0.01$ was obtained. The small effective mass supports the prediction[3] that the minimum of the conduction band occurs at the center of the Brillouin zone.

* Supported in part by the Air Force Office of Scientific Research.
[1] I. Simon, J. Opt. Soc. Am. **41**, 336 (1951).
[2] W. G. Spitzer and H. Y. Fan, Phys. Rev. **106**, 882 (1957).
[3] J. Callaway, J. Electronics **2**, 330 (1957).

KA2. Low-Energy Electron Diffraction from a (100) Silicon Crystal Face and Tests for Contamination from the Ambient.* H. E. FARNSWORTH AND R. E. SCHLIER, *Brown University.*—A diffraction pattern has been observed after heating *in vacuo* 980°C for 2 hours but not after heating at 770°C for 15 hours. Improvement in the pattern intensity was effected by argon-ion bombardment and annealing. The pattern was similar to that previously reported for germanium,[1] i.e., half-integral order diffraction beams were observed in the (110) azimuth but not in the (100) azimuth. Also, the half-integral order beams were nearly extinguished by oxygen adsorption. The oxygen could be removed from the surface by heating at 900°C for 5 min but not at 700°C for one hour. Residual pressures during heating at 1100°C, and immediately following, were too low to permit significant adsorption from the ambient before observations. Separate tests with a tungsten flash filament in another experimental tube showed that oxygen contamination in the ambient during and immediately following the ion-bombardment cleaning process was too small to account for the observed half-integral order diffraction beams in the case of (100) germanium under similar vacuum conditions. It is suggested that the interpretation of the beams from silicon is the same as that proposed for similar beams from germanium.[1]

* This work is supported by a Joint Services Contract with MIT and a subcontract with Brown University, and by a contract with Air Force Cambridge Research Center, Air Research and Development Command.
[1] R. E. Schlier and H. E. Farnsworth, *Semiconductor Surface Physics* (University of Pennsylvania Press, Philadelphia, 1957), p. 3.

KA3. Heat Treatment of Silicon in a Kinetic Vacuum System. W. T. ERIKSEN, *Raytheon Research Division.*—The heat treatment of silicon has been investigated in a kinetic vacuum system. The walls of the containing system remain cool, which gives more confidence in the cleanliness of the ambient. Many experiments can be performed on the same sample, which minimizes the problem of sample inhomogeniety. Samples are annealed at 1200°C until the vacuum attains its limiting value, about 10^{-6} mm Hg and then radiation quenched to room temperature. $(N_D - N_A)$ is increased by quenching from 1200 and subsequently reduced by long annealing at lower temperatures. Activation energy for the annealing process on one sample was 1.2 ev. The change in carrier concentration is always less than 9×10^{14} carriers under any heat treatment conditions. Zone refined samples show very little change in resistivity with heat treatment. That larger changes in carrier concentration with heat treatment are not seen is attributed to the fact that O_2 has been largely eliminated from the samples. Whether the small changes still present are due to residual O_2 or other impurities or characteristics of the silicon lattice itself has not been determined.

KA4. P.M.E. Null Method for Measuring Diffusion Lengths in SI. S. MAYBURG AND L. COHEN, *Sylvania Electric Products.*—A modified P.M.E. technique consists in balancing the magnetic force on the diffusing carriers by an electric field. The carriers are injected uniformly over the surface layer of the specimen at 120 cps by an unfilter-fluorescent-lamp mercury discharge. Using Van Roosbroeck's equations to correct the simplified equations of Aigrain and Bulliard, we get a diffusion length L for thick samples,

$$L = DH(\mu_{nh}+\mu_{ph})(\mu_n+\mu_p)CE(1+S/kD)^{-1},$$

where D is the minority carrier diffusion constant; μ_{nh} and μ_n, μ_{ph} and μ_p are the electron Hall and drift mobilities, the hole Hall and drift mobilities (all functions of resistivity); H, the magnetic field; E, the nulling electric field, determined by the dc current in the sample; S, the surface recombination velocity; and k, the absorption coefficient of the radiation. Since S/kD is small for reasonable surface treatments and the mercury radiation, surface effects are second order. Since carriers are injected at low frequency, no correction for trapping effects need be made. The technique discriminates sharply between homogeneous and inhomogeneous samples; the latter giving rise to large non-nullable photovoltages.

KA5. Fine Structure of Intrinsic Recombination Radiation in Silicon. J. R. HAYNES, M. LAX, AND W. FLOOD, *Bell Telephone Laboratories.*—The fine structure of the intrinsic recombination radiation from Si has been observed using a spectrometer equipped with a diffraction grating. Six lines were resolved, consistent with the interpretation that four involved the emission of phonons of energy $\hbar\omega$ equal to 0.119, 0.083, 0.055, and 0.016 ev for transverse optical, longitudinal optical, longitudinal acoustical, and transverse acoustical modes respectively. The remaining two lines that disappear at low temperatures are interpreted as the absorption of transverse acoustical and longitudinal acoustical phonons. These absolute values for the phonon energies and the energy gap E_g are obtained by comparing absorption and emission of the same phonon, using the relation $h\nu = E_g \pm \hbar\omega$ for the minimum energy of the emitted photon. Our values for E_g are 1.153 ev at 0°K and 1.107 ev at 295°K with a temperature coefficient of 2.3×10^{-4} ev/degree near room temperature. Values obtained for the acoustical phonon energies as well as those for the energy gap are in good agreement with those obtained from absorption data by Macfarlane and Roberts.[1] From the small energy difference between the longitudinal phonons J. C. Phillips has estimated that the conduction band energy minimum is located approximately at 0.83 $(\pi/a)(1,0,0)$.

[1] G. G. Macfarlane and V. Roberts, Phys. Rev. **98**, 1865 (1955); Macfarlane, McLean, Quarrington, and Roberts, Phys. Rev. (to be published).

KA6. Work Function Studies of Silicon Single Crystals.* J. A. DILLON, JR., *Brown University.*—The work functions of a number of silicon single crystals have been studied in the experimental system previously used for germanium. The samples were all p-type with resistivities between 50 and 100 ohm-cm. They were grown in quartz crucibles and had not been subjected to the floating-zone process. Heating the silicon above 1000°C in contact with quartz drastically affected the surface properties and changed the type and resistivity; therefore electrical contact was made by means of a molybdenum clamping arrangement which was shielded from ion bombardment. For the samples which had been subjected to extensive heating at 1000°C and ion-bombardment cleaning, the work function values after radiation quenching from 1000°C were higher than those after annealing at 500°C. The values after quenching were: (100), 4.92 ev; (110), 4.89 ev; (111), 4.77 ev. The values after annealing were: (100), 4.82 ev; (110), 4.70 ev; (111), 4.67 ev. The differences between the quenched and annealed values persisted even after prolonged heating at 1100°C although the values for the (100) and (110) faces changed slightly, possibly due to the extensive thermal etching which occurred when these faces were heated at 1100°C. Oxygen adsorption at room temperature resulted in work function increases, hydrogen exposure resulted in work function decreases only in the presence of a heated filament.

* This work is supported by a Joint Services Contract with MIT and a subcontract with Brown University, and by a contract with Air Force Cambridge Research Center, Air Research and Development Command.

KA7. Zeeman Effect of Impurities in Semiconductors.* BENJAMIN LAX, R. D. PUFF, AND W. H. KLEINER, *Lincoln Laboratory.*—The Zeeman effect of impurity levels can yield information about the band structure of a semiconductor. Thus, in a simple semiconductor with an isotropic carrier of effective mass m^* the $2p_{\pm}$ states are split by an energy $\hbar(eH/m^*c)$ at low enough fields, allowing in principle an experimental determination of m^*. For an anisotropic mass the Zeeman pattern depends on the magnetic field orientation relative to the crystal axes. The pattern has been calculated to second order of perturbation theory for Si and Ge donors. The results apply for Si throughout the range of experimental fields (up to 40 kgauss), but for Ge a better approximation is required for the higher fields. The Zeeman splitting should be resolvable in Si with monovalent impurities when measured at liquid helium temperatures with a high resolution infrared grating spectrometer in the wavelength range 10 to 30 μ. In Ge, longer wavelengths are required unless one considers multivalent impurities with deeper levels. Observation of the Zeeman effect and its anisotropy promises to provide a valuable tool for investigating the band structure of semiconductors where cyclotron resonance is not feasible.

* The research reported in this document was supported jointly by the Army, Navy, and Air Force under contract with MIT.

KA8. One-Dimensional Impurity Bands. H. L. FRISCH AND S. P. LLOYD, *Bell Telephone Laboratories* (introduced by N. B. Hanna).—The (integral) density $n(\epsilon)$ of one-electron energy levels of a one-dimensional "crystal" containing impurities of a single kind is studied in the effective mass approximation. The distribution of impurity atoms (δ-function model, strength $-\alpha$) is assumed to be the Poisson distribution, with (density) parameter λ. Then the electron wave function $\psi(x)$ and its derivative $\psi'(x)$ constitute a two-dimensional Markov process (parameter x), and the joint probability density of ψ, ψ' satisfies a first order partial differential-difference equation (forward equation). The moments $\langle(\psi(x))^r(\psi'(x))^s\rangle$ are obtained easily for small $r+s$. The stationary marginal density $T(z)$ of $z=\psi'/\psi$ (if it exists) satisfies $[d/dz][(z^2+\epsilon)T(z)]+\lambda[T(z+\alpha)-T(z)]=0$ where $\epsilon=(2m/\hbar^2)\times$(energy). It is shown that $n(\epsilon)=\lim_{z\to\pm\infty} z^2T(z)$ if $\int_{-\infty}^{\infty} T(z)dz=1$. A power series in λ and strict upper and lower bounds for $n(\epsilon)$ are obtained for the case $\epsilon\geq 0$. If λ/α is small, the bounds are close to each other. The approximation $T(z+\alpha)-T(z)=\alpha T'(z)$ (good for $\alpha\to 0$, $\lambda\alpha\to$finite) gives the results of the optical model.

KA9. Low-Temperature Fast Neutron Irradiation of Germanium.* J. W. CLELAND AND J. H. CRAWFORD, JR., *Oak Ridge National Laboratory.*—The rate of change of conductivity of n-type single crystal plates of germanium during fast neutron irradiation at a temperature of ~16°K is enhanced over that previously observed at higher temperatures. Annealing studies subsequent to irradiation reveal no evidence of thermally unstable defects between ~10 and ~55°K. Annealing above ~95°K indicates the presence of thermally unstable minority carrier traps of the type previously observed following irradiation at 120°K. The enhanced decrease in conductivity at 16°K compared to that observed at higher temperatures is believed to reflect a greater rate of introduction of defects, many of which anneal at temperatures above 95°K.

* This work was supported by the U. S. Atomic Energy Commission.

KA10. Effect of Monoenergetic Fast Neutrons on N-Type Germanium. S. L. RUBY, F. D. SCHUPP, AND E. D. WOLLEY, *Westinghouse Electric Corporation.*—The present models[1,2] for fast neutron radiation damage are being checked experimentally with monoenergetic neutrons in N-type germanium. The changes in resistivity and Hall coefficients have been determined as a function of neutron flux and energy for N-type germanium having impurity concentrations of about 3×10^{13} cm^{-3}. Both the irradiation and electrical measurements have been made at 77°K. Neutron energies used were 4.7, 2.7, and 1.7 Mev from the $H^3(d,n)H^3$ reaction. The observed changes in resistivity and Hall coefficients are not only lower than the theoretical predictions, but are also less than would be estimated by extrapolating the results obtained from reactor neutron irradiations.

[1] F. Seitz and J. S. Koehler, *Solid State Physics* (Academic Press, Inc., New York, 1956), Vol. 2, p. 305.
[2] J. H. Crawford and J. W. Cleland, *Progress in Semiconductors* (Heywood, London, 1957), Vol. 2, p. 69.

KA11. On the Nature of Radiation Damage in Silicon.* G. K. WERTHEIM, *Bell Telephone Laboratories.*—Bombardment damage in silicon produced by electrons of energy less than 1 Mev consists of groups of imperfections, such as vacancy-interstitial pairs. The differentiation between paired imperfections and isolated point imperfections is made on the basis of mobility and capture cross sections. The former is sensitive to the net charge of the imperfection site while the latter is sensitive to the charge of one of the constituent point defects. The energy level 0.29 ev above the valence band[1] has no effect on mobility when the Fermi level is above it, and reduces mobility when it is below. Measurements of lifetime in n-type material yields a hole-capture cross section for the 0.29 ev level much larger than electron-capture cross section, indicating that the center is negative. These results are consistent provided the 0.29 ev level arises from an imperfection pair in which both members of the pair are charged when the Fermi level is above the level they produce. The bombardment levels located 0.16 ev below the conduction band have also have been investigated. No evidence for the presence of other energy levels has been found from mobility measurements.

* This work was supported in part by the Wright Air Development Center of the U. S. Air Force.
[1] G. K. Wertheim, Phys. Rev. 105, 1730 (1957).

KA12. Abrasive Resistance of Irradiated Diamonds.* A. C. DAMASK,† *Brookhaven National Laboratory.*—The amount of

wear of neutron irradiated diamonds against silicon carbide abrasive is compared with unirradiated diamonds. The volume removed from diamond phonograph needles is calculated geometrically from microphotographs of four groups of six diamonds irradiated with different total fluxes, and an average is taken for each group. For an irradiaton of 2.6×10^{18} NVT fast the hardness is 50% of the unirradiated hardness, and for 7.8×10^{20} NVT fast the hardness is 20%. The densities were measured by flotation in warm thallium malonate solution to an accuracy of about ±0.7%. For the 2.6×10^{18} irradiation the density has decreased by 1% and by 4% for the 7.8×10^{20} irradiation. The data indicate a linear relationship between hardness and density. The decrease of cohesive energy of an irradiated diamond is estimated crudely from the number of broken bonds and the strain energy of the density change. The calculated fractional decrease in cohesive energy is about one half of the fractional decrease in hardness.

* Under contract with the U. S. Atomic Energy Commission.
† Guest Scientist from Frankford Arsenal, Philadelphia, Pennsylvania.

KA13. Expansion of Copper Upon Low Temperature Deuteron Irradiation.* RICHARD WERNER VOOK, *IBM Research Laboratory, Poughkeepsie.*—The increase in linear dimensions of a 99.999% copper foil upon deuteron irradiation was measured directly as a function of integrated flux. Two bombardments were made on the same specimen with integrated fluxes of 3.14×10^{16} d/cm^2 and 7.68×10^{16} d/cm^2, respectively. It was found in both runs that the specific change in length per incident deuteron per square centimeter was 3.8×10^{-21}. This value applies to an average deuteron energy of 8.5 Mev. Measurements of the thermal recovery of the irradiation-induced change in length were also made. If the thermal recovery between the bombardment temperature and room temperature are designated as Stage I (<70°K), Stage II (70–180°K), and Stage III (180–300°K), then the amount of recovery per stage is 64%, 6%, and 26%, respectively. The residual effect remaining at 300°K is 4% of the maximum effect. It is suggested that the defects introduced by the deuteron irradiation are Frenkel pairs and that thermal recovery proceeds by means of their recombination between the bombardment temperature of 17°K and 300°K.

* This work was supported by the U. S. Atomic Energy Commission and was submitted to the University of Illinois in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

THURSDAY AFTERNOON AT 2:00

Manhattan Center

(J. W. BEAMS presiding)

Joint Ceremonial Session of APS and AAPT

Retiring Presidential Address of the American Physical Society

L1. Past and Present Relations of Science and Government in the United States. H. D. SMYTH, *Princeton University.*

(V. E. EATON presiding)

Presentation of the Oersted Medal of the AAPT
Response of the Oersted Medallist

L2. A New Era in Science? J. W. BUCHTA, *University of Minnesota.*

Sixteenth Richtmyer Memorial Lecture of the AAPT

L3. The Approximate Nature of Physical Symmetries. PHILIP MORRISON, *Cornell University.*

FRIDAY MORNING AT 9:15

Terrace Room

(J. RAINWATER presiding)

Pions and Muons

M1. Photoproduction of Positive Mesons from Hydrogen.* W. M. WOODWARD, M. HEINBERG, R. R. WILSON, AND D. ZIPOY, *Cornell University.*—A strong focusing magnet and a counter telescope have been used to measure the cross section of the reaction $\gamma+p\rightarrow n+\pi^+$ at 90° in the laboratory system as a function of the photon energy. The bremsstrahlung from the 1.1-Bev Cornell synchrotron were used and the upper limit of the spectrum was adjusted so that multiple meson production was energetically impossible. The energy of the meson was determined by the magnet, and the mesons were identified by the relative pulse heights given by the counters as well as the range. Liquid hydrogen was used as the target. After passing through the well-known peak at 300-Mev photon energy the cross section (at about 120° in the c.m.) is found to remain roughly constant at about 6μb/sterad from 500 to 900 Mev although there is some indication of another

peak at about 700 Mev. The absolute accuracy is not better than about 50% at the present time pending a determination of the aperture of the magnet. This is being made and the measurements are being extended to other angles and energies.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

M2. Photoproduction of π^0 Mesons from Hydrogen at 500–900 Mev.* P. C. STEIN AND K. C. ROGERS, *Cornell University.*—The photoproduction of single π^0 mesons is being studied at photon energies between 500 and 900 Mev, using the bremsstrahlung beam from the Cornell electron synchrotron. Cross sections are measured by counting the recoil protons from a liquid hydrogen target. Protons are identified by their energy loss in a standard range telescope. A Čerenkov counter is used to discriminate against mesons and multiple electron events. Differential cross sections at meson energies of 60°, 90°, and 120° in the center of mass were measured and the results will be presented.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

M3. Photoproduction of Neutral Pions from Hydrogen in the Region 500–1000 Mev.* J. W. DEWIRE, H. E. JACKSON, AND R. M. LITTAUER, *Cornell University.*—The reaction $h\nu+p\rightarrow p+\pi^0$ is being studied using the bremsstrahlung from the Cornell electron synchrotron. The reaction is identified by detecting the recoil proton in a scintillation counter telescope in coincidence with one of the mesonic decay photons, which is counted in a lead glass shower detector. Copper absorbers in the proton counter define the energy of the incoming photon. Data have been taken in 100-Mev intervals at laboratory angles for the proton of 25°, 41°, and 60°. The differential cross sections for 90° (c.m.) are

$h\nu$(Mev)	$d\sigma/d\omega$(μb/sterad)
550	4.34±0.29
650	4.23±0.25
750	3.72±0.13
850	2.98±0.14
950	1.57±0.12

The quoted errors are statistical. Systematic errors due to uncertainty in the correction for proton absorption and to beam calibration increase with energy and do not exceed 10%. Results at other angles will be presented.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

M4. Diffusion Cloud-Chamber Study of Multiple Photomeson Production in H_2 at the Cornell Synchrotron.* J. M. SELLEN, G. COCCONI, V. T. COCCONI, AND E. L. HART.—A 20-atmos hydrogen filled diffusion chamber operating in a magnetic field of 6 kilogauss has been placed in the 1-Bev bremsstrahlung beam of the Cornell synchrotron. About 40 000 pictures have been taken with this chamber and have yielded approximately 100 events of the type $\gamma+p\rightarrow p+\pi^+ +\pi^-$. These events have been analyzed to yield the total cross section for this reaction as a function of γ-ray energy and to give distributions of angles, momenta, and relative Q's of the particles involved. The bremsstrahlung spectrum used for the determination of the cross section has been obtained from a separate experiment on the electron-positron pairs in these pictures. The experimental distributions of the Q's and the momenta have been compared with the predictions of the statistical model and of the excited model.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

M5. Asymmetry in π^+-Meson Production by Polarized Protons. E. HEER, A. ROBERTS, AND J. TINLOT, *University of Rochester.*—We are studying the azimuthal asymmetry in the production of π^+ mesons in complex nuclei by 210-Mev polarized protons. Such an asymmetry has been observed[1] at 315 and 415 Mev for the process $p+p\rightarrow\pi^++d$. The results obtained for aluminum are shown below; the quantity listed is the asymmetry which would be produced by 100% polarized protons. The asymmetry at 90° is larger than that observed for p-p production at higher energies, has the same (negative) sign, is roughly independent of meson energy, and varies with angle more rapidly than $\sin\theta$. We plan to investigate other elements and π^0 and π^- production.

Meson energy (Mev)	θ lab. 90°	120°	145°
14.5–22.5		−0.494±0.118	
23.5–29.9	−0.624±0.129	−0.185±0.101	−0.213±0.090
28.6–34.3	−0.583±0.115	−0.251±0.090	−0.101±0.130
35.5–40.3		−0.444±0.106	
38.7–43.4	−0.203±0.112	−0.348±0.091	−0.022±0.016
49.0–53.6	−0.488±0.347		

[1] F. S. Crawford and M. L. Stevenson, Phys. Rev. **95**, 1112 (1954).

M6. π^+-P Scattering at 480 Mev.* T. W. MORRIS, D. C. RAHM, R. R. RAU, AND A. M. THORNDIKE, *Brookhaven National Laboratory,* AND W. J. WILLIS,† *Yale University.*—A liquid hydrogen bubble chamber was used to obtain 20 000 pictures in a 480-Mev π^+ meson beam at the Cosmotron. In this focused external pion beam, the numbers of π^+ and protons were approximately equal. Preliminary results on 85 events show that production of an additional pion occurs in 10 cases, or about 12% of the interactions. The angular distribution of the elastic scatterings is given approximately by $(1+4\cos\theta+4\cos^2\theta)$ in the center-of-mass system.

* This work carried out under the auspices of the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.

M7. π^--Proton Scattering at 950 Mev.* A. R. ERWIN, JR., AND J. K. KOPP, *Brookhaven National Laboratory.*—Approximately 1200 π^--proton interactions in a liquid hydrogen bubble chamber were studied to obtain the elastic differential cross section and inelastic partial cross sections at 950±20 Mev mean laboratory energy. Relative cross sections were converted to absolute values using the total cross section obtained by Cool, Piccioni, and Clark[1] with counters. The differential cross section is inconsistent with a resonance of definite total angular momentum and parity and can be fitted by a superposition of partial waves of angular momenta up to 3 $\hbar$ without spin-flip scattering. In the center-of-mass system, 30% of the pions scatter beyond a broad minimum of the cross section at 75°.

* Work carried out under the auspices of the U. S. Atomic Energy Commission.
[1] Cool, Piccioni, and Clark, Phys. Rev. **103**, 1082 (1956).

M8. Comparison of Experimental Results and Theoretical Predictions for the Elastic Scattering of 80-Mev Pions by Nuclei Using the Kisslinger Optical Model.* W. F. BAKER, H. BYFIELD, AND J. RAINWATER, *Columbia University.*—Experimental measurements on the angular distribution of the elastic scattering of 80-Mev π^- mesons by nuclei have been made for angles up to 115°.[1] The energy resolution was sufficient to distinguish, in favorable cases, the strictly elastic scattering leaving the nucleus in its ground state from that leading to the excitation of low-lying nuclear levels. We have carried out a program of calculations using IBM 650 computers[2] to compare the experimental results for carbon with the predicted values using a modified Kisslinger[3] type optical model. A tapered nuclear edge was used and Coulomb effects were included. The results will be presented.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] W. F. Baker, Nevis Cyclotron Laboratories Report No. 48.
[2] We wish to thank Watson Laboratory and Hudson Laboratory for the use of their computing facilities.
[3] L. S. Kisslinger, Phys. Rev. **98**, 761 (1955).

M9. Magnetic Moment of the Free Muon.* T. COFFIN, R. L. GARWIN,† S. PENMAN, L. M. LEDERMAN, AND A. M. SACHS, *Columbia University.*—The measurement of the magnetic moment of the μ^+ meson by magnetic resonance techniques[1] has been extended by using a somewhat higher frequency and a more homogeneous magnetic field. The experimental arrangement was very similar to that previously discussed in which muons were brought to rest with their spins aligned with the magnetic field. A radio-frequency pulse was applied to effect a spin reorientation which was detected by counting the decay electrons emerging after the pulse in a fixed direction. Results are expressed in terms of a g factor which for a spin $\frac{1}{2}$ particle is the ratio of the actual moment to $eh/2m_\mu c$. The most accurate result obtained in a $CHBr_3$ target, is that $g=2(1.0026\pm0.0009)$ compared to the theoretical prediction of $g=2(1.0012)$. Less accurate measurements yielded $g=2.005\pm0.005$ in a copper target and $g=2.00\pm0.01$ in a lead target.

* This research is supported by the U. S. Atomic Energy Commission and the Office of Naval Research.
† Also at I.B.M. Watson Laboratory.
[1] Coffin, Garwin, Lederman, Penman, and Sachs, Phys. Rev. 106, 5 (1957).

M10. Scattering of Mu Mesons from Lead.* P. GOLDSTEIN, B. CHIDLEY, G. HINMAN, R. SUMMERS, AND R. ADLER, *Carnegie Institute of Technology.*—Mu mesons from the Carnegie Institute of Technology synchrocyclotron have been scattered from lead plates. An angular distribution has been measured from 0° to 30° for mesons in the energy range 20 to 25 Mev. The experimental apparatus used was a propane bubble chamber in which a lead plate was mounted. Plate thicknesses employed were 0.0125 in. and 0.022 in. Observations were restricted to mu mesons which stopped inside the chamber and for which the decay electron was visible. Approximately 40 000 events have been analyzed and the results will be compared with the Moliere theory of multiple scattering.

* This work was supported by the U. S. Atomic Energy Commission.

M11. Neutron Production by Fast μ Mesons.* J. K. DE PAGTER AND R. D. SARD, *Washington University.*—An improved experiment on the nuclear interaction of fast μ mesons in Pb has been carried out, using the Washington University magnet cloud chamber and a detector of evaporation neutrons.[1] Special emphasis was given to determining the contribution to the counting rate by real photons in showers started by knock-on electrons. To this end the Pb producer was divided into 1.27-cm slabs with hodoscoped Geiger tubes in between, so that all but the smallest showers were recognizable. The multiplicity of detected neutrons was also recorded. Preliminary analysis gives 1.6×10^{-28} cm²/nucleon for the cross section-neutron multiplicity product for direct nuclear interaction of fast μ mesons at sea level. Analysis of the hodoscope data shows that the contribution from real photons has been effectively eliminated.

* Supported in part by the joint program of the Office of Naval Research, U. S. Atomic Energy Commission.
[1] Stearns, Jones, de Pagter, and Sard, Phys. Rev. 106, 1043 (1957).

M12. Nuclear Interactions of High-Energy μ Mesons. I. B. MCDIARMID, *National Research Council, Canada.*—A multiplate cloud chamber operated under 90 cm of lead at sea level has been used to study nuclear interactions produced by high energy particles most of which could be shown to be μ mesons. Plastic scintillators mounted inside the chamber served as carbon targets and also as part of a selection system which was biased strongly against unwanted events. The following cross sections for μ mesons have been obtained: $5.6\pm1.1\times10^{-30}$ cm²/nucleon for all interactions involving energy transfers ≥50 Mev and $1.7\pm0.6\times10^{-30}$ cm²/nucleon for shower production. It is shown that the main features of the interactions can be understood with the aid of the semi-classical Williams-Weizsäcker method. The cloud chamber results are compared with those of George and Evans[1] who studied nuclear interactions produced in photographic emulsions exposed underground. The μ-meson results are used along with the Williams-Weizsäcker theory to infer photo cross sections in carbon and a nearly constant value of about 10^{-27} cm² is obtained for photons in the energy range 0.1 to 10 Bev with possibly an increase in the region of 10 Bev.

[1] E. P. George and J. Evans, Proc. Phys. Soc. (London) A68, 829 (1955).

Invited Paper

M13. Production of Strange Particles in Pion-Proton Collisions. J. STEINBERGER, *Columbia University.* (30 min.)

FRIDAY MORNING AT 9:45

Empire Suite

(A. KLEIN presiding)

Theoretical Physics III: Various Topics

MA1. Applications of an Explicit Finite Difference Scheme for Numerical Integration of the Time-Dependent Schrödinger Equation.* J. MAZUR, *Dow Chemical Company,* AND ROBERT J. RUBIN, *National Bureau of Standards.*—A stable, explicit, finite difference approximation for numerical integration of the time-dependent Schrödinger equation has been developed. This procedure has been tested with the aid of the ILLIAC (University of Illinois Electronic Digital Computer) for two one-dimensional examples (1) propagation of a Gaussian wave packet for a free particle and (2) oscillation of a Gaussian wave packet in a harmonic oscillator potential field.[1] Our interest in the finite difference scheme has been in the application of the method to the study of a model system undergoing an exchange reaction, $AB+C\rightarrow A+BC$. The results of these calculation for the reaction probability will be described. In addition, the possible application of the foregoing approximation technique to various scattering processes will be discussed.

* The work reported here was started by the authors while at the University of Illinois.
[1] V. Rojansky, *Introductory Quantum Mechanics* (Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1946), p. 115.

MA2. Approximate Solution of Nonlocal Schroedinger's Equation.* A. E. S. GREEN,† *Florida State University.*—The approximate solution of Schroedinger's equation with nonlocal potentials is a matter of increasing importance because

of the recent work of Brueckner, Bethe, and others in which nonlocal potentials arise in the self-consistent nuclear structure calculation. Frahn and Lemmer have related this problem to the solution of Schroedinger's equation with a local potential and a kinetic energy operator with a radially variable mass. A code previously devised for the ORNL Oracle‡ encompasses this problem and hence may be applied to a variety of phenomenological studies involving the use of nonlocal potentials or velocity-dependent potentials. This computer code secures not only the eigenvalues but also the derivatives of the eigenvalues relative to the various parameters (well depth, radius, diffuseness, spin orbit coupling, and velocity dependence) thus extending the usefulness of calculated eigenvalues to a multispace parameter neighborhood. The power of the eigenvalue derivative technique is illustrated by some applications.

* Supported by a grant the U. S. Atomic Energy Commission.
† Now on leave at Los Alamos Scientific Laboratory.
‡ Work carried out with assistance of the ORINS-ORACLE Applications Program.

MA3. Covariance of Wick Products in Lagrangians.* F. J. BELINFANTE, *Purdue University.*—As discussed, e.g., in a preprint[1] of an article never published, for avoiding zero-point energies while yet explaining the Uehling effect in the Lamb shift, observables (and, thence, the Lagrangian L) should be defined by Furry-Oppenheimer's method (1934) as sums of Wick's S products in the interaction picture and should be the transformed thereof in the Heisenberg picture. Thus, in $j^\mu = ie(\bar{\psi}\gamma^\mu\psi^{(+)} - \psi^{(-)}\gamma^\mu\bar{\psi})$, the undors $\psi^{(\pm)}$, if defined in interaction pictures for space-like surfaces t=constant, equal $C^{(\pm)}{}_{\alpha\beta}\psi$ with free-electron Casimir projection operators $C^{(\pm)}{}_{\alpha\beta}$ but are not undors in the Heisenberg picture. Nevertheless even in the Heisenberg picture this j^μ (and not for instance $j_0{}^\mu = ie\bar{\psi}\gamma^\mu\psi$) is a four vector. The reason is the meaninglessness[2] of $j_0{}^\mu$ and of the c numbers $(j^\mu - j_0{}^\mu)$. Therefore Gupta's new plea for using Wick's S products in L is justified.[3]

* Supported by the National Science Foundation.
[1] F. J. Belinfante, "A Position Theory Without Holes," (August, 1953), pp. 26–27. Compare also F. J. Belinfante, Phys. Rev. **75**, 1633 (1949); **93**, 935 (1954); and A. S. Wightman and S. S. Schweber, Phys. Rev. **98**, 812 (1955), footnotes 12 and 47.
[2] F. J. Belinfante, Phys. Rev. **76**, 461 (1949).
[3] S. N. Gupta, Phys. Rev. **107**, 1722 (1957).

MA4. Particle Model in Darling's Theory of Elementary Particles. II. HANS FREISTADT, *The University of British Columbia.*—A model of an elementary particle in Darling's theory,[1] proposed and abandoned[2] several years ago, is considered anew. Instead of complex Hankel functions, which lead to a differential equation for the electromagnetic field without regular solution, the real Bessel function is used in the "world symmetric" wave function. [The possibility of describing charged particles by real wave functions was demonstrated by Schrödinger.[3]] The equation for the electromagnetic field (corresponding to Eq. (5) in reference 2) now has well-behaved solutions; these apparently cannot be exhibited in closed form in terms of conventional functions, but could be obtained by numerical integration. Thus, there is no compelling reason to abandon the model proposed in reference 2, although at this stage it appears unlikely that such a naive model would yield a reasonable mass spectrum.

[1] B. T. Darling, Phys. Rev. **80**, 460 (1950); **91**, 1252 (1953).
[2] H. Freistadt, Phys. Rev. **92**, 1015 (1953).
[3] E. Schrödinger, Nature **169**, 538 (1952).

MA5. Generalization of Quantum Mechanics.* T. E. PHIPPS, JR., *Operations Evaluation Group.*—The postulates of quantum mechanics are re-examined for possible deviations in the nuclear domain. To make use of the only available guidance (correspondence), one must retain the framework of linear algebra. This rules out modification of the multiplicative associative law, or laws involving addition. There remains only the commutative law: any departure must affect the Heisenberg postulate. A generalized form, $pq - qp = S$, is examined. This relation amounts to defining p as the non-Hermitean operator $(\partial/\partial q)S$. The classical form of this p definition permits equations of motion to be set down by direct correspondence with Hamilton-Jacobi mechanics, *viz.*, $H(q_i, p_i, t)\Psi = -(\partial/\partial t)S\Psi$, $p_i\Psi = -(\partial/\partial q_i)S\Psi$, $-P_i\Psi = (\partial/\partial Q_i)S\Psi$, where P_i, Q_i are constants. Ordinary quantum mechanics corresponds to S being constant $(S = \hbar/i)$, with $\Psi = \Psi_0(q_i, t)\exp[(i/\hbar)(-\Sigma_i P_i Q_i + E't_0)]$. Since S stands in the same relation to space and time differentiation, it can more generally be any Lorentz scalar function. Hence the formalism comprehends in addition to states that satisfy the Heisenberg postulate others that do not. The latter are found in a particular relativistic formulation to describe electrons in bound "nuclear" states of real energy but imaginary momentum. The results appear possibly applicable to the description of nuclear beta and other processes.

* Work done at MIT.

MA6. Feynman Integral in a Canonical Formalism. JAMES L. ANDERSON, *Stevens Institute of Technology.*—Feynman[1] has shown how it is possible to recast his integral over all paths formulation of quantum mechanics in terms of canonical variables. Although he presented the results only for systems in flat space and containing only quadratic velocity terms, it is possible to apply the formalism to quite arbitrary Hamiltonians. The formulation in terms of canonical variables has several advantages over a strictly Lagrangian approach. Among other things, transformation theory is more easily discussed. Since what corresponds, in the Lagrangian formalism, to a canonical transformation is in general a very complicated transformation involving both coordinates and velocities. In addition the measure for the functional integral is fixed once and for all as contrasted to the situation in the Lagrangian formulation where it depends explicitly on the form of the Lagrangian. Finally it is possible, in a quite straightforward manner to obtain the Schrödinger equation directly from the integral without the necessity of actually evaluating any integrals. In addition to treating the above points in detail we shall show the connection between the formalism expressed in terms of canonical and Lagrangian variables.

[1] R. P. Feynman, Phys. Rev. **84**, 108 (1951).

MA7. Compton Proton Wavelength as the Quantum of Length. LEONARD S. LEVITT, *Stevens Institute of Technology* (introduced by Winston H. Bostick).—Most of the experimentally measured lengths pertaining to fundamental nuclear forces are integral multiples of the Compton wavelength, λ_0 of the proton, where $\lambda_0 = \hbar/m_p c = 1.32 \times 10^{-13}$ cm. Table I shows the fundamental nuclear lengths as multiples of λ_0 (which may conveniently be called the "compton"). The probable error is given where available. It must be emphasized that all of these lengths, so important for their bearing on the theory of nuclear forces, are *experimental*, not theoretical quantities. Furthermore, the nuclear unit radius R_0 for nuclei of $A \geq 200$

TABLE I.

Experimental quantity	Length in cm $\times 10^{13}$	Length in "comptons"
p-p singlet force, effective range	2.65 ±0.08	2.01 ±0.06
n-p singlet force, effective range	2.7 ±0.5	2.0 ±0.4
n-p coherent scattering length	3.96 ±0.2 (3.78 ±0.03)	3.00 ±0.2 (2.88 ±0.02)
Triplet n-p scattering length	5.38 ±0.02	4.06 ±0.02
Singlet n-n scattering length	15.9	12.0
Singlet p-p scattering length	17.2	13.0
Singlet n-p scattering length	23.7 ±0.05	18.0 ±0.04

has recently been found to be 1.32×10^{-13} cm ($=1.00\ \lambda_0$), and the values obtained for R_0 of light nuclei by some ten different methods range between 1.1 and 1.5×10^{-13} cm. Thus it appears that the true radius of the proton may well be its Compton wavelength.

MA8. Classical Photon-Like Fields. J. S. LOMONT, *IBM, Ossining.*—Simple classical wave equations for zero rest mass particles which eliminate potentials have been developed. Moses[1] has shown that the free-field Maxwell equation can be written in the form $\alpha^\mu\nabla_\mu\psi=0$, where the four α's are Dirac matrices satisfying $\alpha^1\alpha^2=i\alpha^3$(cycl.1,2,3), and ψ is a linear function of the field strengths. This equation can be generalized to describe zero rest mass particles of any spin >0. For spin s the α's are $4s$-dimensional and satisfy the simple relations $[\alpha^i,\alpha^j]_+=2\delta_{ij}$, $\alpha^1\alpha^2=i\alpha^3$(cycl.), $\alpha^0=I$ (the unit matrix). The components of ψ are not arbitrary; in a particular representation of the α's $2s-1$ components of ψ must be zero. Particles of given momentum can only have spin sparallel and antiparallel to the momentum. Quantization is being investigated. However, since no invariant Lagrangian is known, quantization presents difficulties.

[1] H. E. Moses, IMM-NYU 238 (1957).

MA9. "Spin" in Classical Mechanics. RALPH SCHILLER, *Stevens Institute of Technology.*—A generalization of the classical Hamilton-Jacobi theory leads to a classical equation almost identical with the Pauli equation. This generalization is consistent with the dynamical equations of charged particles and is necessary if all the possible families of trajectories in configuration space are to be incorporated in the Hamilton-Jacobi theory. The equations of the generalized Hamilton-Jacobi theory are identical with the Pauli equation through the first power in $\hbar$, and, as is the case for the Schrödinger equation, the classical solutions agree with those found by the WBK method to the same approximation. In addition, this classical theory of spin permits one to construct for an infinitesimal time interval the propagation kernel of the Pauli equation. This kernel is identical with the one suggested by Feynman in 1948. The theory indicates that the spin of the electron is not an internal property of the electron, but is rather a consequence of its translational motion. The quantization of spin arises because of requirements of continuity for the wave function and is similar to the quantization of angular momentum in the Schrödinger theory. A similar approach is applicable in relativistic electron theory.

MA10. Functional Integrals in Field Theory. T. F. MORRIS, *McGill University.*—A simple definition of integration with respect to a set of anticommuting variables has been obtained. The usual results for the field propagators are obtained. It is observed that the integrals for the complete nucleon propagators are solutions, subject to certain boundary conditions, of a functional differential equation which has the form of a Schroedinger equation for a free particle in an infinite dimensional space. This allows the nucleon propagator to be expressed in a new form

MA11. Connection of Phase Shift and Potential for the Dirac Equation.* F. PRATS AND J. S. TOLL, *University of Maryland.*—Using a method of Gel'fand and Levitan, Jost, and Kohn[1] have shown how, for a Schrödinger equation with central potential, the potential can be determined (through the spectral function) by the pnase shift, plus the energy and another arbitrary parameter for each bound state. We present a similar procedure, appropriately generalized to matrices, for the Dirac equation with a central potential with $\int_0^\infty r^m V(r)dr$ finite, $(m=0,1,2)$. From the analytic properties[2] in the k plane of the radial wave functions, a spectral function is introduced. The relation between eigenfunctions for two different potentials involves a kernel, from which the potential difference is obtained. The equation (analogous to the Gel'fand-Levitan integral equation) for this kernel can be constructed from the spectral function and eigenfunctions of the "comparison" potential and the spectral function for the unknown potential.

* Supported in part by the U. S. Air Force through the Office of Scientific Research of the Air Force Research and Development Command.

[1] Jost and Kohn, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **27**, No. 9 (1953).

[2] D. S. Carter, Princeton University Ph.D. Dissertation (1952, unpublished).

MA12. Generation of Action-Angle Variables in the Many-Body Problem.* G. J. YEVICK AND J. K. PERCUS, *Stevens Institute of Technology.*—In carrying out an investigation of the modes of oscillation of many-body systems,[1] we have attempted to find suitable action-angle variables.[2] We first proceed classically and then transform to quantum-mechanical action-angle variables. In order to do this, we have found it necessary to consider quantum-mechanical generating functions other than the usual type $S(p,q)$. Major difficulties arise in the ordering of the noncommuting quantities. Conditions which the quantum-mechanical generating functions must satisfy are obtained by insisting that the new coordinates and momenta again be canonically conjugate. In general, the resulting equations appear to be very difficult to solve because of unlimited possibilities in the ordering of operators, only one of which is correct. We have succeeded in finding the generating functions for the transformation from the free particle to the harmonic oscillator. This was only possible for two of the four standard classical forms; the other two apear hopelessly involved. The difference between the classical and quantum-mechanical generating functions in this example manifests itself as a term proportional to $\hbar^2$.

* Supported by Office of Naval Research.

[1] J. K. Percus and G. J. Vevick, Bull. Am. Phys. Soc. Ser. II, **2**, 204 (1957).

[2] G. J. Yevick and J. K. Percus, Bull. Am. Phys. Soc. Ser. II, **2**, 204 (1957).

FRIDAY MORNING AT 9:30

Panel Room

(G. N. GLASOE presiding)

Nuclear Reactions II

N1. The 4.97-Mev Level in Ne^{20}. H. E. GOVE, A. E. LITHERLAND, AND A. J. FERGUSON, *Chalk River Laboratories.*—The reaction $F^{19}(p,\gamma)Ne^{20}$ has been employed to study the properties of the 4.97-Mev level in Ne^{20} using the Chalk River electrostatic generator. Gamma rays from proton capture at two resonances at 0.669 Mev ($J=1+$) and at 1.092 Mev (spin unknown) have been measured in two 5 in. by 4 in. NaI crystals. Coincidence yield curves established that this level was fed by a primary capture gamma ray at both resonances. The 4.97-Mev level decays with greater than

95% probability to the first excited state at 1.63 Mev. This result recently received independent confirmation.[1] Triple correlation measurements established that the 4.97-Mev level did not have zero spin. Since it is fed by a primary gamma-ray transition from a $J=1+$ state it is unlikely to have a spin greater than three. The possible participation of the 4.97-Mev level in the $O^{16}+\alpha$ stellar reaction[2,3] then suggests that it has $J=1-$ or $2+$ with the absence of ground-state transitions somewhat favoring the latter value.

[1] Kruse, Bent, and Lidofsky, Bull. Am. Phys. Soc. Ser. II, 2, 351 (1957).
[2] F. E. Salpeter, Phys. Rev. 107, 516 (1957).
[3] A. G. W. Cameron, Chalk River Report CRL-41, June, 1957.

N2. Level Density in Ne^{22}. C. D. Goodman, *Oak Ridge National Laboratory,** and K. S. Lee, *MIT.*—Level densities deduced from (α,p) reactions are not in agreement with those from other experiments.[1] Nitrogen induced reactions are well suited for deducing level densities.[2] 30-Mev alpha particles on F^{19} would produce the compound nucleus Na^{23} at the same excitation energy as 27 Mev N^{14} on Be^9, if the compound nucleus can be formed in these ways. Therefore, the energy distributions of protons from $Be^9(N^{14},p)Ne^{22}$ and from $F^{19}(\alpha,p)Ne^{22}$ have been compared at the above-mentioned bombarding energies of N^{14} and α which are available respectively at ORNL and at MIT. The (N^{14},p) reaction leads to a level density formula $\omega(E)=C\exp 2[a(E-b)]^{\frac{1}{2}}$ with $a=2.6$ Mev^{-1}, $b=4.9$ Mev. The (α,p) reaction at 120° laboratory angle shows agreement with the nitrogen reaction from about 14 Mev to 22 Mev excitation of Ne^{22}, but transitions to levels below 14 Mev seem to be enhanced in the (α,p) case.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Nuclear Company.
[1] G. Igo and H. E. Wegner, Phys. Rev. 102, 1364 (1956).
[2] C. D. Goodman and J. L. Need (to be published).

N3. Angular Distributions of Inelastically Scattered Protons.* H. A. Lackner and H. J. Hausman, *The Ohio State University.*—The 6.2-Mev external proton beam of the Ohio State University Cyclotron is being used to bombard thin targets of various isotopes. The external beam is focused by a pair of quadrupole focusing magnets and bent through an angle of 15 degrees by a conventional sector-type electromagnet. Detection of charged reaction particles is performed by means of a scintillation detector mounted vertically through the lid of the scattering chamber. The lid of the scattering chamber rotates on ball-bearings permitting detection at various angles. In preliminary experiments, angular distributions of protons inelastically scattered from thin targets of magnesium, evaporated onto thin gold backings, have been investigated between laboratory angles of 15 deg and 160 deg. The angular distributions were performed on the proton groups leaving Mg^{24} in its first and second excited states of 1.38 Mev and 4.14 Mev. The experimental angular distributions are compared with predictions based upon Butler's theory[1] on direct-type nuclear reactions. Details of the experiment and results will be described.

* Supported in part by the U. S. Atomic Energy Commission.
[1] S. T. Butler, Phys. Rev. 106, 272 (1957).

N4. A New Excited State in Al^{25}. A. E. Litherland, H. E. Gove, and A. J. Ferguson, *Chalk River Laboratories.*—The rotational interpretation of the low lying states of Al^{25} has made the observation of higher members of the rotational bands of interest.[1] The $Mg^{24}(p,\gamma)Al^{25}$ reaction has been used to search for states of Al^{25}. A coincidence yield curve showed the presence of a weak resonance at 1.84 Mev and measurements showed the presence of gamma rays of energy approximately 1.61 Mev, 2.44 Mev, and 4.05 Mev. The 1.37-Mev gamma ray from inelastic scattering was not observed. These gamma rays are interpreted as a transition to the ground state and a cascade transition through the 1.61-Mev excited state. The measured branching ratio is 2:3 with the ground-state transition being the stronger. The value of $\omega\gamma$ for the ground-state transition was measured to be 0.003 ev. Since the 1.84 Mev resonance is not observed in the scattering of protons by Mg^{24} it is not possible to deduce the value of the gamma-ray width. The angular distributions of the 4.05-Mev and 2.44-Mev gamma rays have been measured. The measurements definitely eliminate $\frac{1}{2}$, $\frac{3}{2}$, and $\frac{5}{2}$ for the angular momentum of the capturing state but do not discriminate between $\frac{1}{2}$ and 9/2. The implications of this new state to the collective rotational model will be discussed.

[1] A. E. Litherland *et al.*, Phys. Rev. 102, 208 (1956).

N5. Lifetime of the 1.78-Mev State in Si^{28}.* S. M. Shafroth and E. N. Strait, *Northwestern University,* and R. A. J. Levesque, *University of Maryland.*—The 1.78-Mev state in Si^{28} is being investigated by measuring the Doppler shift of the gamma emitted in the $Si^{28}(p,p')$ reaction at the 3.10-Mev resonance. The gamma energy is measured at 0° and 140° with respect to the beam direction by means of a scintillation counter and a Radiation Counter Laboratories Inc. 256-channel analyzer. Thin layers of Si about 100 A thick have been evaporated on to 0.05-mil nickel foil. The silicon has been bombarded with protons from the Northwestern University 5-Mev Van de Graaff through the foil so that recoil silicon nuclei go forward into vacuum and then decay. The observed Doppler shift in vacuum is about $\frac{1}{2}$%. A background resulting from Si on the gold beam stopper contributes about one third of the 1.78-Mev gammas. Experiments will be discussed in which the Doppler shift is measured for recoil silicon nuclei stopping in various media, and a lifetime value will be given.

* Supported by the National Science Foundation.

N6. Cross Section for the $S^{32}(n,\alpha)Si^{29}$ Reaction as a Function of Energy. H. W. Schmitt, *Oak Ridge National Laboratory.*—The $S^{32}(n,\alpha)Si^{29}$ cross section has been measured as a function of energy in the range above 1.4 Mev. A double back-to-back ionization chamber was used with krypton gas. Monoenergetic neutrons from the $T(p,n)He^3$ reaction were incident on lead sulfide and U^{235} deposits, situated back-to back in the center plate of the chamber; fragments from the neutron-induced fission of the U^{235} were counted to determine the number of incident neutrons. Alpha-particle yields were determined separately in the forward and backward hemispheres, i.e., at 0° to 90° and 90° to 180° in the laboratory system; the total n,α cross section was obtained from the sum. The cross section in general increases with increasing energy above 1.4 Mev, although several strong peaks are observed. The results agree qualitatively, in the region of overlap, with those of Hurlimann and Huber.[1]

[1] T. Hurlimann and P. Huber, Helv. Phys. Acta 28, 33 (1955).

N7. Proton Strength Functions from (p,n) Reaction Cross Sections.* J. P. Schiffer and L. L. Lee, Jr., *Argonne National Laboratory.*—Measurements of the cross section for compound-nucleus formation by protons have been extended to thirty-one target elements, $37 \leq A \leq 133$, with bombarding energies ranging from 2 to 4 Mev.[1] The thick target yields for the (p,n) reaction were divided by a barrier penetrability factor to yield a quantity closely related to the proton-width strength function of nuclei. A maximum in this quantity was observed at atomic weight 68 and some evidence for a secondary maximum found at atomic weight 50. These maxima were tentatively assigned to peaks in the *S*- and *D*-

wave strength functions.[2] Angular distribution measurements taken in an attempt to confirm these assignments have not yielded conclusive results. The data also indicate that the assumptions of a square well and a spherical nucleus are perhaps not fully justified in calculating the barrier penetrabilities in this region of atomic weight.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. P. Schiffer and L. L. Lee, Jr., Phys. Rev. 107, 640 (1957).
[2] B. Margolis and V. F. Weisskopf, Phys. Rev. 107, 641 (1957).

N8. Alpha Particles and Protons from the Nitrogen Bombardment of Aluminum. A. ZUCKER, *Oak Ridge National Laboratory.*—Aluminum targets, about 0.36 mg cm^{-2} thick, were bombarded with 28-Mev nitrogen ions. The compound nucleus, Ca^{41}, is excited to 40 Mev and may decay by proton emission to K^{40}, and by alpha emission to A^{37}. Energy distributions for protons and alpha particles were measured at six angles from 0 deg to 90 deg. The number of protons or alphas per unit beam, divided by the channel energy and the capture cross section, plotted as a function of the square root of the excitation energy in the residual nucleus yields a value of a in the level density formula $\omega = C \exp[2(aE)^{\frac{1}{2}}]$. The data fit this formula well at all angles giving $a = 5.0 \pm 0.2$ for K^{40}, and $a = 4.1 \pm 0.3$ for A^{37}. Angular distributions were also measured and are reasonably isotropic for protons, whereas they show a definite forward peak for alpha particles. An even-odd effect was found in the level density of the residual nuclei, K^{40} having about 2.5 times the level density of A^{37}. In general, the nitrogen-aluminum reaction bears out the predictions of the statistical theory for the decay of a compound nucleus.

N9. Nitrogen-Induced Nuclear Reactions in Potassium. M. L. HALBERT, J. J. PINAJIAN, AND A. ZUCKER, *Oak Ridge National Laboratory.*—Bombardment of K^{39} by 28-Mev nitrogen ions results in the compound nucleus Fe^{55} excited to more than 40 Mev. For eight of the residual nuclei, representing end products of at least ten reactions, excitation functions have been measured by activation. Thick targets, containing natural K, were bombarded in the ORNL 63-in. cyclotron. When required, nickel foils were used to degrade the beam energy below 28 Mev. Each target was then chemically processed to separate the different elements and the various fractions were beta-counted. Preliminary results are given below. In each case, we list first the observed residual nucleus; second, the simplest particle or group of particles leading to this nucleus by emission from Fe^{55}; and third, the measured cross section in millibarns at 27 Mev. (1) Fe^{52}, n: 0.3; (2) Mn^{55}, p: 3; (3) Mn^{54m}, p: 0.2; (4) Cr^{49}, α: 0.2; (5) Mn^{51}, $pn+2n$: 5; (6) V^{48}, αp: 5; (7) V^{47}, $\alpha pn+\alpha 2n$: 1; (8) Ti^{45}, 2α: 1. Also observed was 9-min Fe^{55}, probably due to reactions on K^{41}. Reactions involving K^{41} might also account for an appreciable part of the yields of the other residual nuclei, particularly the first four listed. Some of the data have been used in approximate calculations based on the statistical theory of compound-nucleus decay. The Mn^{52}/Fe^{52} ratio furnishes information on the odd-even factor in the level density.

N10. Levels in Cr^{50}, Cr^{52}, Cr^{53}, and Cr^{54}.* D. M. VAN PATTER, W. C. PORTER, M. A. ROTHMAN, AND C. E. MANDEVILLE, *Bartol Research Foundation.*—Inelastic proton spectra from targets of natural chromium and targets enriched in Cr^{50}, Cr^{53}, and Cr^{54} have been studied for bombarding energies in the region of 4.3 to 4.6 Mev using a double-focusing magnetic spectrometer, at angles of observation of 91.5° and 136.2°. The enriched targets were prepared by the vacuum evaporation of Cr_2O_3 from a small carbon crucible mounted on a tungsten filament onto gold leaf backings. Surveys were taken up to at least 2.0-Mev excitation. The following level energies in kev were determined: Cr^{50} 780±3; Cr^{52} 1432±5; Cr^{53} 562±3, 1006±4, and 1287±5; Cr^{54} 842±6. The new level in Cr^{50} occurs at the energy expected for the first 2+ state, and hence the recent assignment of Sinclair[1] of a 787 ±10-kev γ ray observed from the Cr^{50} $(n,n'\gamma)$ reaction has been verified. Inelastic proton groups corresponding to the known second excited states of Cr^{52} and Cr^{54} were not of sufficient intensity to be observed.

* Assisted by the Air Force Office of Scientific Research of the Air Research and Development Command.
[1] R. M. Sinclair, Phys. Rev. 107, 1306 (1957).

N11. Excited States of Cu^{64} and Cu^{66}.* R. P. DE FIGUEIREDO, M. MAZARI, AND W. W. BUECHNER, *MIT.*—The proton groups arising from the deuteron bombardment of thin targets enriched in Cu^{63} and Cu^{65} have been studied with a broad-range magnetic spectrograph at various angles of observation. The deuterons were accelerated to energies ranging from 6.00 to 6.55 Mev by the MIT-ONR accelerator. The Q values for the transitions to the ground states of Cu^{64} and Cu^{66} are, respectively, 5.691±0.008 and 4.832±0.008 Mev. In the excitation region up to 3.80 Mev, sixty-five levels in Cu^{64} and fifty-five levels in Cu^{66} have been measured. The first ten levels in Cu^{64} are at 0.159, 0.277, 0.343, 0.360, 0.574, 0.607, 0.664, 0.743, 0.877, and 0.894 Mev, and the first five levels in Cu^{66} are at 0.183, 0.272, 0.383, 0.462, and 0.589 Mev, the uncertainty in all of these levels being ±0.008 Mev.

* This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

N12. (d,p) Reactions of the Nickel Isotopes Ni^{58} and Ni^{60}.* C. H. PARIS AND W. W. BUECHNER, *MIT.*—Thin targets enriched in Ni^{58} and Ni^{60}, as well as targets of natural nickel, have been bombarded with deuterons from the MIT-ONR accelerator, and the resulting proton groups have been studied with the broad-range magnetic spectrograph at angles of 30, 50, and 90 deg. An incident deuteron energy of 7.01 Mev was used. The Q values of the (d,p) reactions leading to the ground states of Ni^{59} and Ni^{61} were found to be 6.775 and 5.597 Mev, respectively. In Ni^{59}, the first nine levels are measured at 0.338, 0.464, 0.878, (1.186), (1.299), (1.337), 1.680, 1.754, and 1.768 Mev; while in Ni^{61} the first eight levels are measured at 0.070, 0.285, (0.657), 0.913, 1.103, 1.135, 1.188, and 1.454 Mev. The levels in parentheses are the ones for which the assignment is still preliminary. For each of these nuclei, a large number of higher excited states has been observed.

* This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

N13. Coulomb Excitation of Xenon. G. F. PIEPER AND C. E. ANDERSON, *Yale University,* AND N. P. HEYDENBURG, *Carnegie Institution of Washington.*—Normal Xe and two enriched samples of Xe, one enriched in the light isotopes the other in the heavy isotopes, were Coulomb excited by 6.45-Mev alpha particles. The following first excited state transitions $(0^+ - 2^+)$ were observed in the even-even isotopes: Xe^{128}, 445-kev; Xe^{130}, 535-kev; Xe^{132}, 670-kev. The gamma ray at 875-kev previously reported[1] for Xe^{134} was found to be due to O^{17} following the strong $N^{14}(\alpha,p)O^{17}$ reaction in the small amount of N^{14} present in the gas samples. No gamma ray was observed for Xe^{134}. The following gamma rays were found in the odd isotopes: Xe^{129}, 290-kev; Xe^{131}, 290-kev and 355-kev. Relative $B(E2)$ values will be given.

[1] N. P. Heydenburg and G. M. Temmer, Bull. Am. Phys. Soc. Ser. II, 1, 164 (1956).

FRIDAY MORNING AT 9:45

Grand Ballroom

(H. D. HAGSTRUM presiding)

Symposium of the Division of Electron Physics

NA1. Sputtering Experiments in the Laboratory for Mass Spectrography at Amsterdam. J. KISTEMAKER, *Laboratory for Mass Spectrography*, Amsterdam. (30 min.)

NA2. Recombination in Ionized Gases. J. SAYERS, *University of Birmingham, England.* (30 min.)

NA3. Some Recent Developments in the Theory of Scattering of Electrons by Atoms. S. BOROWITZ, *New York University.* (30 min.)

NA4. Atomic-Beam Studies of Scattering of Electrons by Atoms. B. BEDERSON, *New York University.* (30 min.)

Business Meeting of the Division of Electron Physics

(To be held during Session NA at such time as seems good to the Chairman.)

FRIDAY MORNING AT 9:45

Boston-Washington Room

(J. W. BEAMS presiding)

General Physics

P1. Stabilization of the Pinch Effect Using a Longitudinal Magnetic Field.[1] M. A. LEVINE, *Air Force Cambridge Research Center*, L. S. COMBES, W. FITZSIMMONS, AND S. ZIMMERMAN, *Tufts University.*—The pinch or Bennett-effect[2] (the self-magnetic contraction of an ionized gas carrying a large Amperian current) has been shown to be unstable.[3–5] The mixing of a longitudinal field with the pinch field has been considered and found inadequate.[6] However, the *H*-centered pinch[7] with a completely trapped longitudinal field giving an orthogonal rotation of the *H*-vector across the plasma boundary gives almost complete stability. In fact, when used in conjunction with a conducting shell, this configuration is completely stable. Experimental evidence of this in a gas at 10 microns using image convertor pictures is reported.

[1] This work antedates that reported by M. Rosenbluth, *Third International Conference of Ionization Phenomena in Gases* (Venice, June, 1957).
[2] W. H. Bennett, Phys. Rev. **45**, 890 (1934).
[3] M. Kruskal and M. Schwarzchild, Proc. Roy. Soc. (London) **A223**, 348 (1954).
[4] Bostick, Combes, and Levine, Final Report AF19(122)-89, (Tufts University) (unpublished).
[5] J. Tuck and M. Kruskal, Los Alamos Sci. Lab. Rept. LA-1716 (November, 1953) (unpublished).
[6] R. H. Lovberg, 10th Ann. Gaseous Elec. Conf. Mass. Inst. Tech. (October, 1957).
[7] M. A. Levine and L. S. Combes, Tufts University Scientific Note No. 16 (December, 1954) (unpublished).

P2. High-Field Plasma Accelerator. DAVID FINKELSTEIN, *Stevens Institute of Technology and New York University.*—A device for the production of relativistic plasmas has been designed using a fast capacitor bank being assembled at Stevens. It is to be an induction accelerator acting on an ionized gas. Because of hydromagnetic instabilities associated with the self-magnetic field of the beam, a high external field is to be used, using a modification of the pulse techniques employed by Furth, Levine, and Wanniek.[1] The coil is being designed and built with the aid of Brookhaven National Laboratory. It consists of a single heavy-walled turn shaped to satisfy the betatron equilibrium and weak-focusing criterion. The device, called the Megatron (mega-gauss betatron) has an orbit radius $R=1$ inch and the expected electron energy is 100 Mev. The capacitor bank and switching methods will be described.

[1] Furth, Levine, and Wanniek, Bull. Am. Phys. Soc. Ser. II, 1, 190 (1956); 2, 7 (1957). H. P. Furth and R. W. Wanniek, Rev. Sci. Instr. 27, 195 (1956).

P3. A Method of Accelerating a Gas to High Velocities with a Magnetic Field.[*] R. M. PATRICK, *AVCO Research Laboratory* (introduced by A. Kantrowitz).—A coaxial cylindrical geometry has been used to accelerate a gas between two conducting cylinders. The acceleration mechanism works as follows. A low-frequency (1 kilocycle) discharge through a solenoid placed around the coaxial cylinders produces a uniform magnetic field in the axial direction inside the cylinders. At the time of maximum axial field strength a discharge between the two cylinders is initiated from a condenser bank with a ringing frequency of over 200 kilocycles. The body force due to the radial current between the two cylinders and the azmuthal magnetic field produced by the current flowing in the cylinders results in an acceleration away from the point of initial breakdown in the axial direction. Conditions have been produced where the mean free path for ions and electrons is longer than their gyro radius in a magnetic field, and with the mean free path small compared to the radial distance between the cylinders. Measurements have been of the light emitted by the accelerated gas, the local magnetic field strength, the radial gas current, and the velocity of the gas.

[*] This research was supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.

P4. Molecular Dissociation Following Beta Decay in CH_3T. FRANCES PLEASONTON AND ARTHUR H. SNELL, *Oak Ridge National Laboratory.*—Monotritiated methane is dissociated following nearly every beta transformation of the constituent T to He^3. Usually the neutral He^3 simply departs from the molecule, leaving CH_3^+. Sometimes, however, additional

hydrogens are split off, yielding CH_3^+, CH^+, and C^+. When this happens, the hydrogens are usually neutral. The ions CH_2^+, CH^+, and C^+ are observed in approximately equal abundance. Traces are also found of C^{++} and CH_2^{++}, but not of CH^{++} and CH_3^{++}. There is slight evidence for the He^3 remaining bound as CH_3He^3, CH_2He^3, and $CHHe^3$ for at least as long as it takes the ions to pass through the analyzing spectrometer.

P5. Possible Sources of a Lunar Atmosphere. L. B. BORST, *New York University*, AND W. F. EDWARDS, *California Institute of Technology*.—Radio astronomy observations[1] are best interpreted by assuming a lunar atmosphere of $2\text{–}6\times10^{-13}$ terrestrial atmospheres. Since the gravitational field is unable to hold terrestrial gases, O_2, N_2, A, and etc., krypton and xenon are proposed as the only permanent gases. Of the sources considered, three are quantitatively possible (a) spontaneous fission of U^{238}, (b) radioactive decay of primeval I^{129}, and (c) trapped primeval Kr and Xe. Rejected sources are (a) cosmic ray neutron fission, and (b) neutron fission from O^{18} (α,n) Ne^{21}. The atmospheric composition will be sensitive to the formation mechanism.

[1] B. Elsmore, Phil. Mag. 2, 1040 (1957).

P6. Production of X-Rays in Aurorae. PAUL J. KELLOGG, *University of Minnesota and Naval Research Laboratory*.—Calculations have been carried out on the mechanism proposed[1] to explain the production of x-rays during auroral displays.[2] The steady state of the collision of an infinite gas cloud with the earth is treated, using a magnetohydrodynamic approach which differs somewhat from the conventional approach in that pressure and collisions are neglected. The earth makes a hole in the cloud and the surface of the hole has a characteristic thickness l given by $(1/l^2)=(8\pi e^2N_0/c^2)[(1/M)+(1/m)]$ where N_0 is initial ion density of the cloud, M,M are proton and electron masses. If this length is much less than the curvature of the surface, a one-dimensional approximation is justified. In this approximation, the acceleration of the electrons is independent of N_0. Results of calculations of the acceleration of the electrons will be presented.

[1] P. J. Kellogg, Phys. Rev. 108, 1093 (1957).
[2] J. R. Winckler and L. Peterson, Phys. Rev. 108, 903 (1957).

P7. New Acceleration Mechanism for Auroral Particles.* S. F. SINGER, *University of Maryland*.—Acceleration of solar protons (mean energy ~20 kev) to auroral energies (~1 Mev as deduced from atmospheric penetration) is a longstanding problem. Our acceleration mechanism operates near the earth on "trapped" protons; these oscillate back and forth along magnetic force lines while drifting azimuthally to produce the magnetic storm ring current.[1] We describe two basic processes. (1) "Fermi collisions" with hydromagnetic waves which are excited by solar protons and guided by lines of force; their existence also explains observations of geomagnetic micropulsations. (2) Induction acceleration via the earth's field by bunched protons; this also explains observations of vlf radio emissions. The two processes in "push-pull" keep the proton's pitch angle from becoming too small too soon.[2] Thus the proton gains much energy before it breaks out of the trap and into the atmosphere. This statistical acceleration process leads to an energy *spectrum* as suggested observationally. The push-pull scheme may also be important for galactic cosmic ray acceleration.[3]

* Assisted by the Air Force Office of Scientific Research.
[1] S. F. Singer, Trans. Am. Geophys. Union 38, 175 (1957).
[2] C. Y. Fan, Phys. Rev. 101, 314 (1956).

P8. Sputtering by Ions with Energies above 50 kev. DAVID T. GOLDMAN* AND ALBERT SIMON, *Oak Ridge National Laboratory*.—Sputtering calculations at low energy involve complicated analysis of surface interactions. As the energy of the ion increases, however, a simplifying feature emerges. The range of the incident ion becomes large compared to the mean free path of the primary and knock-ons. Hence the displacement rate may be taken as uniform in depth and relatively simple solutions are obtained for the sputtering rate. A solution is obtained by assuming that the average number of secondaries, $\bar{\nu}$, are all produced at the initial displacement point. In addition, the macroscopic scattering and absorption cross sections are adjusted to make the average number of collisions of each particle equal to the actual average over the secondaries. The problem can then be treated as one-velocity diffusion. The resultant sputtering ratio, R, varies with incident energy, E, incident angle, ψ, and mass ratio, $\mu=M_t/M_i$, as

$$R\sim\frac{\ln E}{E\cos\psi}\,\frac{\mu}{(1+\mu)^2}$$

Details of more exact solutions and numerical results will be presented.

* Present address: University of Maryland.

P9. High-Intensity, Low-Energy, N_2^+, O_2^+ Ion Source.* C. J. COOK AND J. R. PETERSON, *Stanford Research Institute*.—In order to facilitate certain very low-energy atomic and molecular impact studies requiring comparatively high beam currents, an electrodeless, radio-frequency-excited ion source has been developed from the ideas of Thonemann.[1] A 25-mc rf generator is inductively coupled to a plasma whose density is increased by an axial magnetic field. Operating at a pressure of $5\text{–}8\times10^{-4}$ mm Hg in the plasma region, N_2 or O_2 gas is consumed at about 0.6 cc/min. The 1 cm-diameter extraction port is differentially pumped. Focusing characteristics of the beam are optimized at extraction energies of 2.5–3.0 kev. Beams of 2 ma have been observed under these conditions, with energy half-widths of 8–15 ev, and consisting of 60–80% $N_2^+(O_2^+)$ and 40–20% $N_1^+(O_1^+)$. A periodic axially symmetrical electrostatic field collimates the ion beam to an area less than 0.6 cm^2 at 12 cm from the source. The narrow energy spread in the beam will allow relatively large currents to be obtained, by deceleration, at very low energies. The source is also applicable to high-energy accelerators requiring a monoenergetic ion source. The present source has delivered milliampere beams for about 250 hours with negligible deterioration.

* This work has been supported by the National Advisory Committee for Aeronautics.
[1] P. C. Thonemann and E. R. Harrison, AERE, GP, R1190 (Harwell, 1955).

P10. Stripping Cross Sections of Negative Hydrogen Ions between 0.4 and 2.0 Mev in H_2, O_2, A, and CO_2. P. H. ROSE, R. J. CONNOR, AND R. P. BASTIDE.—Measurements of the stripping cross sections of H^- ions in gas targets were made in the energy range 0.4 to 2.0 Mev. The positive and negative beam components emerging from the gas target were measured using Faraday cages and sensitive galvanometers in the conventional manner. A temperature compensated calorimeter with a sensitivity of 0.5 mw per centimeter deflection and time constant of 5-minutes was used to measure the neutral component of the beam. The results show the expected variation of cross section with Z and extrapolate smoothly on to the cross sections obtained by Stier and Barnett[1] at lower energies.

[1] P. N. Stier and C. F. Barnett, Phys. Rev. 103, 896 (1956).

P11. The Residual Concentration of a Daughter Substance Removed by a Bimolecular Reaction. JEROME ROTHSTEIN,* *Edgerton, Germeshausen & Grier, Inc.*—Consider an initial concentration N_0 of a parent substance transforming monomolecularly into a daughter substance. The differential

equation giving the concentration n of the latter subject to the condition that the daughter substance is removed by a bimolecular reaction is reduced to the form $y' = e^{-x} - y^2$. The solution is given in graphical and tabular form, and several approximations analyzed. The measurement of decay constants in terms of reaction constants and vice versa is discussed. Possible applications to studies of chemical kinetics, lattice defects, order-disorder transformations in solids, electronic processes in semiconductors and phosphors, recombination of ions in liquids and gases, and tracer studies *in vitro* and *in vivo* are mentioned.

* Work done at the U. S. Army Signal Engineering Laboratories.

P12. Investigation of Equivalent Single Ion, Na^+, Activities of Drilling Mud Filtrates.* LEONARD B. LIPSON AND HAROLD L. OVERTON, *University of Houston* (introduced by Leonard B. Lipson).—The analysis of data from electrical logs made in bore holes makes use of $E_{sp} = -K \log a_w/a_{mf}$, where E_{sp} is the spontaneous potential observed in the bore hole, K is a temperature dependent constant, a_w is the mean ionic activity of the connate water in the formations penetrated, and a_{mf} is the mean ionic activity of the drilling mud filtrate in the bore hole. Since drilling mud filtrates are made up of complex mixtures of organic and inorganic substances, it is extremely difficult to determine representative mean ionic activities. However, an approximate solution to the equation has been used for sometime as a practical expedient, by assuming that both the connate waters and drilling mud filtrates are pure NaCl solutions. An improved solution to the problem is presented in this paper, by using a method which enables determination of the equivalent single ion, Na^+, activity of the ions in drilling mud filtrates by comparison with standard NaCl solutions, which are separated by cationic membranes from the filtrates. In the range of interest, the mean ionic activity and the equivalent single ion, Na^+, activity are approximately equal. Two hundred and fifty filtrates from laboratory and field muds were investigated. Systematic deviations from pure NaCl solutions are explained in terms of gross chemical properties of the filtrates.

* This research was supported by Schlumberger Well Surveying Corporation.

P13. Kinks in Properties of Liquids. GEORGE ANTONOFF, *New York*, AND ALEXIS YAKIMAC, *Miami Beach*.—Investigation of latest data indicates invariably that kinks occur according to a definite law in all cases known. They indicate that the structure of matter is entirely different than is generally supposed.

FRIDAY MORNING AT 9:15

Governor Clinton

(R. M. BOZORTH presiding)

Ferro-, Ferri-, Antiferro-Magnetism

PA1. High-Frequency NMR in Antiferromagnetic CoF_2 and FeF_2. Temperature Dependence of M. V. JACCARINO, R. G. SHULMAN, AND J. L. DAVIS, *Bell Telephone Laboratories*, AND J. W. STOUT, *University of Chicago*.*—NMR of F^{19} nuclei in antiferromagnetic single crystals of CoF_2 ($T_N = 37.7°K$) has been observed in the frequency range 130–180 Mc/sec, with external fields of 3–9000 oe. As in the case of MnF_2,[1] the temperature dependence of the sublattice magnetization, M, was determined with high accuracy, by extrapolating the frequency for resonance to zero external field. In the temperature range 1.3–20.4°K the deviation of the magnetization, $M(0) - M(T)$, follows a $T^{3.0}$ law. From measurements made with $H_0 \leq 3$ oe at 1.3°K and 4.2°K we have obtained $\nu_0(0) \pm 0.010$ Mc/sec. The field dependence of the resonances revealed that the spin susceptibility with $H_0 \parallel [001]$, is large even at the lowest temperatures.[2] Similar measurements were made on FeF_2 ($T_N = 78.4°K$) in the frequency range 173–185 Mc/sec. From these we have obtained $\nu_0(0) = 183.218 \pm 0.015$ Mc/sec.

* The work at the University of Chicago was supported in part by the Office of Naval Research.
[1] V. Jaccarino and R. G. Shulman, Phys. Rev. 107, 1196 (1957).
[2] J. W. Stout and L. M. Mattarrese, Revs. Modern Phys. 25, 338 (1953).

PA2. Domain Structure in Paramagnetic Salts at Very Low Temperatures. R. C. SAPP, *University of Kansas*.—The magnetic properties of single crystal ferric ammonium alum below its transition point are different in some respects from those of antiferromagnetic crystals such as chromic methylamine alum.[1] The initial susceptibility as a function of entropy shows a broad flat maximum rather than a sharp peak. As a function of applied field at constant entropy, the differential susceptibility displays a small anisotropy but no maximum in the presence of moderate fields. Such observations may be related to the hypothesis by Kittel[2] of the formation of ferromagnetic domains, saturated by dipolar forces at temperatures below 0.1°K, in a system of dipoles on f.c.c. or b.c.c. lattices. Such domains are compared with Neel's antiferromagnetic domains[3] as to their magnetic and thermal properties.

[1] C. W. Dempsey and R. C. Sapp, Fifth Inter. Conf. on Low Temp. Phys. and Chem. (Madison, Wisconsin, August 26–31, 1957).
[2] C. Kittel, Phys. Rev. 82, 965 (1951).
[3] L. Neel, Proc. Conf. Theoret. Phys. Tokyo (1953), p. 711.

PA3. Magnetic and Electrical Properties of Nickel-Iron Ferrite. I. Effects of Magnetic Heat Treatment.* K. DWIGHT AND N. MENYUK, *Lincoln Laboratory*.—Measurements of the anisotropy constants of nickel-iron ferrites and nominally nickel ferrites of unknown composition have been widely reported in the literature.[1] Most of the results quoted are in relative agreement at room temperature with a wide divergence at 77°K. At the latter temperature Healy[2] obtained a positive value for K_1 while other authors have obtained negative values which are widely scattered. We have measured the crystalline anisotropy of a single crystal of nickel-iron ferrite of composition $Fe_{1.0}^{3+}[Ni_{0.5}^{2+}Fe_{0.5}^{3+}Fe_{0.5}^{2+}]O_4$ after heat treating it in a magnetic field at *ca* 100°C along each of the principal crystalline axes. Measurements of K_1 at room temperature after the heat treatment along different axes showed little variation; however, as the temperature is reduced further, the divergence increases. At 77°K the value of K_1 can be either positive or negative, depending upon the heat treatment. The divergent results had previously been attributed to compositional variations but our experiments show that a knowledge of sample history is essential for a valid analysis of nickel-iron ferrite data from different sources.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with MIT.
[1] Bozorth, Tilden, and Williams, Phys. Rev. 99, 1788 (1955).
[2] D. W. Healy, Phys. Rev. 86, 1009 (1952).

PA4. Magnetic and Electrical Properties of Nickel-Iron Ferrite. II. Low-Temperature Transition.* N. MENYUK AND K. DWIGHT, *Lincoln Laboratory.*—The crystalline anisotropy of a single crystal of nickel-iron ferrite

$$Fe_{1.0}^{3+}[Ni_{0.8}^{2+}Fe_{0.36}^{2+}Fe_{0.8}^{3+}]O_4$$

undergoes a transition slightly above the temperature of liquid helium. The transition is sharp, with over 80% of the anisotropy change occurring in the three degree interval from 6.0°K to 9.0°K. Above the transition region the anisotropy is small and dependent upon the state of the sample (see preceding abstract). Upon cooling through the transition point with the sample oriented in a saturating magnetic field, the direction of the field determines the easy magnetization direction in the low-temperature region. When a (110) faced disk sample is cooled with the magnetic field in a [111] direction, the other [111] axis on the same face, which is 70° removed, is found to be an equally easy magnetization direction. This seems to indicate that, unlike magnetite, the crystal symmetry remains unaltered through the transition. The saturation moment of the sample remains unchanged through the transition. However, the electrical conductivity undergoes a low-temperature transition, indicating an electron ordering phenomenon.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with MIT.

PA5. Onset of Ferromagnetism with Increasing Fe Content in Fe-Cr Alloys. A. ARROTT AND H. SATO, *Ford Motor Company.*—A study of magnetic isotherms from 2°K to 300°K in the Cr-rich Fe-Cr alloys has been carried out. Earlier work[1] on the paramagnetic compositions 1, 5, 10, and 15% Fe has been supplemented by measurements on weakly ferromagnetic 20 and 27% Fe. The M^2 *vs* H criterion for ferromagnetism[2] has been applied to show that the 20% alloy has a Curie temperature just above liquid helium temperatures while the 27% alloy becomes ferromagnetic near 160°K. The nonlinear variation of Curie temperature and magnetic moment with composition observed here is in contrast to the linear behavior in the Fe-rich alloys. Rather than a collective electron approach suggested by the temperature dependence of the paramagnetic alloys an attempt is made to explain the results on the basis of nearest neighbor iron-iron interaction alone, the importance of the nearest neighbor interaction having been well illustrated by the Fe-Al system.[3] A modified Bethe type calculation for the magnetic properties of a disordered alloy has been tried with a certain amount of success in fitting the observations.

[1] A. Arrott, Boston Magnetism Conf. Am. Inst. Elec. Engrs. (1956), p. 285.
[2] A. Arrott, Phys. Rev. (to be published).
[3] H. Sato and A. Arrott, J. Appl. Phys. (to be published).

PA6. Study of Manganese Ferrite-Chromites by Neutron Diffraction.* S. J. PICKART, *U. S. Naval Ordnance Laboratory, Brookhaven National Laboratory, and University of Maryland.*—The magnetization of a series of ferrimagnetic compounds, $(MnFe_{2-t}Cr_tO_4)$ $(0 \leq t \leq 2)$, has been reported by Gorter[1] to be at variance with the Néel antiparallel model. For this reason a low-temperature neutron diffraction study of two or these compounds ($t=1.0$ and 1.5) where the discrepancy is pronounced has been undertaken. Measurements with the application of an external field at low temperatures gave information on the nuclear structure parameters, the moments of the individual A and B sublattices, and their variation with temperature. From the diffraction patterns one may conclude that for these compositions there occurs no long-range ordered arrangement of angles within sublattices of the type postulated by Yafet and Kittel,[2] at least down to liquid helium temperatures.

* This work was carried out at Brookhaven National Laboratory under the auspices of U. S. Atomic Energy Commission and National Security Agency.
[1] E. W. Gorter, Philips Research Repts. 9, 403 (1954).
[2] Y. Yafet and C. Kittel, Phys. Rev. 87, 290 (1952).

PA7. Neutron Diffraction Investigation of the 119°K Transition in Magnetite.* WALTER C. HAMILTON, *Brookhaven National Laboratory* (introduced by J. M. Hastings).—Neutron diffraction studies of synthetic single crystals of magnetite indicate that the transition to the orthorhombic form at 119°K is an order-disorder transition and confirm the ordered model proposed by Verwey *et al.*[1] The forbidden (002) reflection has been observed, and, when a magnetic field is applied at 40° to the c axis in the (110) plane during cooling in order to remove the a-b twinning, changes in intensity confirm the ordering and indicate that the ferric ions lie in rows along the [110] direction perpendicular to the field, and the ferrous ions in rows along the [110] direction in the plane of the field and the c-axis; the magnetic moments of all ions lie along the c axis.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] Verwey, Haayman, and Romeijn, J. Chem. Phys. 15, 181 (1947).

PA8. Defects on a Dipole Lattice.* A. ISIHARA, *University of Maryland.*—Effects of defects on dipole interactions in a simple cubic lattice are calculated. When the concentration of defects is small, thermodynamical functions are linearly dependent on the concentration. The Curie temperature in the three-dimensional lattice is raised or lowered linearly with the concentration according to whether the defects have stronger or weaker dipole interactions with their neighbors than the interactions which the rest of atoms have. Lattice vacancies also reduce the Curie temperature. The specific heat and electric susceptibility of defect lattice are calculated. In the presence of an homogeneous electric field, there exists a critical field which is influenced by defects.

* This work was supported by the U. S. Air Force through the Air Force Office of Scientific Research.

PA9. Observation of Magnetic Domains in Some Ferrospinels and Compounds Related to Magnetoplumbite Utilizing the Faraday Effect. R. C. SHERWOOD, J. P. REMEIKA, AND H. J. WILLIAMS, *Bell Telephone Laboratories.*—Magnetic domains have been observed by means of the Faraday effect in thin (~0.003 cm) crystals having the hexagonal magnetoplumbite structure and in lithium ferrite. A series of compositions having the general formula $PbFe_{(12-x)}Al_xO_{19}$ was investigated. This technique was previously used for observing domains in thin films of Fe-Ni by Fowler and Fryer,[1] in crystals with the garnet structure by J. F. Dillon,[2] and in crystals of $MgFe_2O_4$ by P. A. Miles.[3] We have also observed domains in crystals of $MgFe_2O_4$, in agreement with the latter, and in thin films formed by evaporating $MgFe_2O_4$. Thin specimens (~0.01 cm) of Cd and Zn ferrites were found to be transparent at the red end of the visible spectrum while Co, Ni, and Cu ferrites were opaque. The Faraday rotation was 1100°/cm for $MgFe_2O_4$, 1000°/cm for $Li_{0.5}Fe_{2.5}O_4$, and 4500°/cm for $PbFe_{11}Al_1O_{19}$. Absorption coefficients were measured for these two compounds for radiation having wave lengths from 0.2 μ to 20 μ. Low values were obtained between approximately 0.65 μ and 12 μ. Domains were also observed with a snooperscope utilizing only infrared radiation.

[1] Charles A. Fowler, Jr., and E. M. Fryer, Phys. Rev. 104, 552 (1956).
[2] J. F. Dillon, Jr., Bull. Am. Phys. Soc. Ser. II, 2, 238 (1957).
[3] P. A. Miles, Progr. Rept. No. 21, p. 19 (Laboratory for Insulation Research MIT.

PA10. Exchange Resonance Experiments on Ferrimagnetic Single Crystal Garnets.* SIMON FONER, *Lincoln Laboratory.*—

Recent magnetic investigations[1] on some rare-earth iron garnets showed compensation points and indicated that relatively low effective fields act on the rare-earth ion. Pulsed fields[2] and radiation of 36 kmc/sec and 70 kmc/sec were employed to observe exchange resonance in some of these garnets from 4.2°K up to the compensation point. Techniques, similar to those used earlier for antiferromagnetic resonance experiments[3] in MnF_2 and Cr_2O_3, were employed. From these exchange resonance results and magnetic moment measurements, values of the exchange field acting on the rare-earth ion were determined as a function of temperature. The results appear to be somewhat smaller than those calculated using the more indirect magnetization measurements. Effects of applied field, anisotropy and g-value dependences are discussed. Detailed results for gadolinium iron garnet[4,5] and preliminary results for other garnets are presented.

* The research reported in this document was supported jointly by the Army, Navy, and Air Force under contract with MIT.
[1] R. Pauthenet, Compt. rend. **242**, 1737 (1956).
[2] S. Foner and H. H. Kolm, Rev. Sci. Instr. **28**, 799 (1957); **27**, 547 (1956).
[3] S. Foner, Phys. Rev. **107**, 683 (1957).
[4] A preliminary report of this work was included in a paper (30–4) presented at the Fifth Inter. Conf. on Low Temp. Phys. and Chem. (Madison, Wisconsin, August, 1957).
[5] This garnet crystal was kindly furnished by Dr. W. P. Wolf and Dr. G. P. Rodrigue of Harvard University.

PA11. Theory of Double Resonance in Nearly Compensated Ferrimagnetics. E. SCHLÖMANN, *Raytheon Manufacturing Company.*—The microwave properties of nearly compensated ferrimagnetics placed in a dc magnetic field, a strong rf magnetic field (pumping field) parallel to the dc field, and a weak rf magnetic field perpendicular to the dc field are discussed. For zero pumping field, the theory predicts two absorption lines associated with the two possible modes of gyration of the sublattice structure.[1] The two modes are excited by circularly polarized radiation of opposite senses of polarization. Their frequencies depend on the dc field, the exchange coupling, and the anisotropy fields acting on the two sublattices. If the frequency of the pumping field equals the sum of the two resonant frequencies the pumping field can transfer power to the two sublattice modes. Unstable growth of these modes occurs as the amplitude of the pumping field approaches a critical value approximately equal to the geometric mean of the line widths of the two resonances. Potential applications of this effect with regard to microwave amplification will be discussed.

[1] R. K. Wangsness, Phys. Rev. **97**, 831 (1955); Am. J. Phys. **24**, 60 (1956).

PA12. Magnetic Properties of the Spinel Series $MnCr_{2-t}Al_tO_4$. P. L. EDWARDS, *U. S. Naval Ordnance Laboratory and University of Maryland.*—The saturation moment M_0 of the normal spinel $MnCr_2O_4$, which has been reported as 1.25 μ_B[1] (corrected value), differs from the 1 μ_B required by an antiparallel arrangement of saturated A and B sublattices. Gorter[2] suggested that this might be caused by angles on the B sites according to the Yafet and Kittel (Y and K) model. The series $MnCr_{2-t}Al_tO_4$ seemed a good system with which to test the Y and K model. The cell edge varies linearly with t, being 8.432 A for $MnCr_2O_4$ and 8.205 A for $MnAl_2O_4$, which, considered with an x-ray evidence that at least 95% of the aluminum goes on the B sites, indicates that the entire series is essentially normal. M_0 is 1.16 μ_B for $t=0$ increasing to 1.37 μ_B at $t=0.8$, dropping to 1.25 μ_B at 1.0. For higher t values the materials could not be saturated by a field of 13 000 oersteds. The magnetization curves are normal and T_c drops from 52.5°K±2 for $t=0$ to 30°K±3 at $t=1.4$. The data are consistent with the Y and K model if reasonable variations of the molecular field coefficients with cell size and temperature are allowed.

[1] McGuire, Howard, and Smart, Phys. Rev. **86**, 599 (1952).
[2] E. W. Gorter, Philips Research Repts. **9**, 403 (1954).

PA13. Effective Relaxation Parameters in Ferrimagnetic Resonance. ROALD K. WANGSNESS, *U. S. Naval Ordnance Laboratory.*—The effect of the sublattice structure upon ferrimagnetic resonance when simple damping terms are included in the equations of motion is considered. It can be shown that the apparent ferromagnetic behavior of an arbitrary number of sublattices can be described in terms of an effective relaxation parameter (inverse of relaxation time). In general, the compensation point for this effective parameter will be different from those for magnetization and angular momentum, and the extrapolation of the apparent ferromagnetic behavior through the compensation region leads to a negative value of the absorption coefficient in the immediate vicinity of the compensation point. The exact expression for the steady state susceptibility tensor for a two sublattice system also yields the apparent ferromagnetic behavior, and, when evaluated at the compensation points, admits of the possibility of opposite signs for the absorption at the compensation points for angular momentum and effective relaxation parameter. Some consequences of these results for the description of resonance in the compensation region will be discussed.

PA14. Microwave Resonance and Structure Changes in Chromium Substituted Spinels. T. R. MCGUIRE AND S. W. GREENWALD, *U. S. Naval Ordnance Laboratory.*—Chromium rich nickel ferrite-chromite spinels as well as these compounds with small amounts of Al and Zn substituted for Fe and Ni, respectively, have been studied by microwave resonance absorption and x-ray diffraction. Magnetization measurements also have been made, some of which were previously reported.[1] In $NiOAl_{0.35}Cr_{1.8}Fe_{0.35}O_3$ a shift occurs in g value from approximately 1.6 just below the Curie temperature (−30°C) to a very large value at −145°C where a structure change from cubic to tetragonal takes place. For certain other compositions there are double resonances at low temperatures. Another important feature is that in the $NiOCr_tFe_{2-t}O_3$ system, complex crystallographic distortions take place when $t \geq 1.25$. As the temperature is lowered, changes from cubic to tetragonal occur and for compositions $t=1.75-1.85$ further distortion to orthorhombic have been observed. In the tetragonal phase c/a ratios are <1 when $t<1.85$ and >1 when $t>1.85$. These complex and large distortions are similar to those found in the $FeOCr_tFe_{2-t}O_3$ system by Francombe.[2]

[1] T. R. McGuire and S. W. Greenwald, Bull. Am. Phys. Soc. Ser II, **2**, 22 (1957).
[2] M. H. Francombe, J. Phys. Chem. Solids (to be published).

PA15. Ferrimagnetic Resonance in Single Crystal Magnesium Ferrite. HENRY S. BELSON AND C. J. KRIESSMAN, *Remington Rand Univac.*—A single crystal of magnesium ferrite which exhibits very narrow resonance line widths has been grown by a flux melt technique. The ferrimagnetic resonance behavior of this crystal has been studied as a function of temperature between −195°C and 200°C. Over most of this temperature range a marked dependence of half-width on crystallographic direction is observed. The difference of the half-widths in the [111] and [100] directions, which at −195°C is greater than a factor of two, decreases with increasing temperature until at about 200°C the half-widths are about 35 oersteds in any direction. At room temperature the half-width is 23 oersteds in the [100] direction and 43 oersteds in the [111] direction. Both K_1 and K_2 have been measured as a function of temperature, and K_1, which is -3.9×10^4 erg/cm³ at room temperature, varies as M_s to the sixth power. The spectroscopic splitting factor g decreased from 2.205 at −195°C to 2.007 at 200°C, and has a value of 2.035 at room temperature.

SESSION Q

FRIDAY AFTERNOON AT 2:00

Governor Clinton

(B. LAX presiding)

Ferroelectricity, Magnetism

Q1. Switching Time of $BaTiO_3$ Single Crystals at High Voltage. HENRY L. STADLER, *Bell Telephone Laboratories.*—The switching time of $BaTiO_3$ has been measured at higher voltages than those applied previously by W. J. Merz.[1] By the use of 2 μsec wide pulses having rise times of less than 10^{-9} sec, the switching time has been measured as function of voltage V applied to a crystal 7.5×10^{-3} cm thick. The switching time τ can be represented approximately as $\tau=kv^{-1}$ from 100 v up to 1300 v applied. The shortest switching times, 7.0×10^{-9} sec, are less than half the time taken by a longitudinal sound wave front to move through the thickness of the crystal, 14.9×10^{-9} sec.

[1] W. J. Merz, Phys. Rev. **95**, 690 (1954); J. Appl. Phys. **27**, 938 (1956).

Q2. Temperature Dependence of the Breakdown Field of $BaTiO_3$. P. H. FANG AND W. S. BROWER, *National Bureau of Standards.*—The dc breakdown field has been measured for ceramic $BaTiO_3$ as a function of the ambient temperatures. The breakdown field shows, in general, a temperature dependence of the thermal breakdown type where the breakdown field decreases as the temperature is increased. Similar finding was reported by Sarafanov. But in addition to this general behavior, the breakdown field dips down strongly and shows minima at the critical temperatures of the phase transformations. This seems to indicate a process of polarization breakdown, and is most pronounced near the orthorhombic-tetragonal transition temperatures. From the numerical data for the breakdown field, in combination with the data for the dependence of the coercive voltage on the thickness of single crystal $BaTiO_3$ a lower estimation can be made on the thickness of the surface layer of $BaTiO_3$. The calculation is based on the assumption that the major part of the voltage drop is across the surface, and the least value of the voltage for breakdown of the surface layer is given by the extrapolation of the coercive voltage to zero thickness of the crystal, which is found to be of the order of 1 volt. The breakdown field at room temperature is about 20 kv/cm. Therefore, the surface must be thicker than 5×10^{-6} cm.

Q3. Nonisomorphism of Ferroelectric Phases and Superstructures in $(NH_4)_2SO_4$ and $(NH_4)_2BeF_4$.* R. PEPINSKY, Y. OKAYA, K. VEDAM, AND S. HOSHINO, *Pennsylvania State University.*—$(NH_4)_2SO_4$[1] and $(NH_4)_2BeF_4$[2] become ferroelectric below −49.5°C and −97°C, respectively. Although these crystals were reported as isomorphous,[3] re-examination by x-rays reveals differences in room-temperature symmetries and in directions of polar axes in the ferroelectric phases. Cell constants, in A, are[3] $a=7.49$, $b=10.39$, $c=5.89$ for $(NH_4)_2BeF_4$ and $a=7.729$, $b=10.560$, $c=5.951$ for $(NH_4)_2SO_4$. The room-temperature space group for both is *Pnam* if superstructuring is disregarded; superstructuring appears in all $(NH_4)_2BeF_4$ and some $(NH_4)_2SO_4$ samples, and doubles b and c, leading to space group *Acam*. Below its Curie point $(NH_4)_2BeF_4$ has a doubled, with symmetry $Ac2_1a$. Nonsuperstructured $(NH_4)_2SO_4$ shows neither dimensional doubling nor change in systematic absences at low temperature; the space group is $Pna2_1$. Polar directions observed dielectrically are b in $(NH_4)_2BeF_4$ and c in $(NH_4)_2SO_4$, in agreement with space-group requirements. X-ray, dielectric and thermal measurements are reported on $(NH_4)_2(BeF_4,SO_4)$ and other K_2SO_4-type crystals.

* Supported by U. S. Air Force Office of Scientific Research, U. S. Army Signal Corps Engineering Laboratories, and U. S. Atomic Energy Commission.
[1] B. Matthias and J. P. Remeika, Phys. Rev. **103**, 262 (1956).
[2] R. Pepinsky and F. Jona, Phys. Rev. **105**, 344 (1957).
[3] R. W. G. Wyckoff, *Crystal Structures* (Interscience Publishers, Inc., New York, 1951).

Q4. Dielectric and Thermal Studies of Ferroelectric Transitions in $(NH_4)_2SO_4$ and $(NH_4)_2BeF_4$.* S. HOSHINO, K. VEDAM, Y. OKAYA, AND R. PEPINSKY, *Pennsylvania State University.*—Measurements of dielectric properties, specific heats, and thermal expansions of the ferroelectric transitions in $(NH_4)_2SO_4$[1] and $(NH_4)_2BeF_4$[2] and mixed crystals of these have been performed under various conditions. It is found that the nature of the transition is affected by the previous history of the samples: i.e., heat treatment, application of electric fields, etc. For example, some samples of $(NH_4)_2BeF_4$ which do not show double ferroelectric hysteresis loops characteristic of a first-order transition exhibit this property after thermal annealing. A sample of $(NH_4)_2SO_4$ which was annealed at 75°C shows a typical lambda-type specific heat anomaly, while the sample without heat treatment shows quite different behavior. Results will be discussed in the light of a parallel structural study.

* Supported by U. S. Air Force Office of Scientific Research, U. S. Army Signal Corps Engineering Laboratories, and U. S. Atomic Energy Commission.
[1] B. T. Matthias and J. P. Remeika, Phys. Rev. **103**, 262 (1956).
[2] R. Pepinsky and F. Jona, Phys. Rev. **105**, 344 (1957).

Q5. Anomalous Dielectric Absorption and Ferroelectric Transitions in Alums.* K. VEDAM and R. PEPINSKY, *Pennsylvania State University.*—Examination of the results of Guillien[1] and Le Montagner[2] on dielectric properties of alums reveals that the temperature T_m at which the dielectric loss reaches a maximum is frequency-dependent, and that this anomalous absorption can be represented by Debye's theory of relaxation. No anomaly could be detected by the above investigators at the ferroelectric transition temperatures.[3] Redetermination of the dielectric behavior of $(NH_4)Fe(SO_4)_2\cdot12H_2O$ by us at a number of frequencies between 10 kc and 50 Mc reveals small but reproducible anomalies in ϵ' and ϵ'' at 88 K. Similar anomalies have been detected at microwave frequencies by Griffiths and Powell.[4] Deuteration of the alum increases the value of T_m, but does not alter the transition temperature. Similar observations are reported for other ferroelectric alums.

* Supported by U. S. Air Force Office of Scientific Research and U. S. Army Signal Corps Engineering Laboratories.
[1] R. Guillien, Cahiers phys. **11**, 17 (1942).
[2] Le Montagner, thesis, University of Paris (1956).
[3] R. Pepinsky and K. Vedam, Phys. Rev. (to be published).
[4] J. H. E. Griffiths and J. A. Powell, Proc. Phys. Soc. (London) **65A**, 219 (1952).

Q6. Magnetic Dependence of Ultrasonic Attenuation in Metals at Low Temperatures.* R. W. MORSE, H. V. BOHM, AND D. GAVENDA, *Brown University.*—At low temperatures

the dominant mechanism of ultrasonic attenuation in pure metals is interaction with conduction electrons. This attenuation is strongly affected by a magnetic field. Helium temperature measurements are reported at frequencies from 8 to 100 Mc for fields up to 10 000 gauss in both polycrystal and single crystal samples of indium, tin, copper, aluminum, and zinc. The measurements include longitudinal and shear waves for various orientations of H. The effect depends on the parameter kl, where k is the propagation constant of the wave and l is the electron mean-free-path. When $kl<1$ the attenuation falls monotonically with applied field, varying as H^{-1} when the radius of the electron orbit $r<l$. When $kl>1$, the attenuation generally goes through a series of maxima and minima before decreasing monotonically. The resonances are found in both poly and single crystal samples. The observations in copper and indium and consistent qualitatively with resonances occurring for coincidences of the electron orbit diameter and the ultrasonic wavelength. The results in tin are more complicated suggesting the superposition of another effect which, in contrast to the first, causes a large increase in attenuation with increasing magnetic field. This is strongly frequency-dependent and at 50 Mc results in an attenuation for large fields twice that at zero field.

* Supported in part by the U. S. Air Force through the Office of Scientific Research of the Air Force Research and Development Command.

Q7. Magnetic Susceptibilities of Dilute Magnesium Alloys. W. R. DATARS, M. GARBER, W. G. HENRY, AND L. KUHL, *National Research Council, Canada.*—The magnetic susceptibilities of dilute solutions in magnesium of Ag, Cd, In, Tl, and Al have been determined. Specimens were chill cast in the range of compositions 0 to 5 at % and measured at room temperature. The addition at 1 at % In, Cd, Ag progressively decreases χ_A. This effect is opposite to that observed in Cu- and Ag-base alloys by Henry and Rogers who found χ_A to decrease with increasing solute valence. For the series Mg-Al, In, Tl, χ_A decreases linearly with respect to the row of the periodic table from which the solute comes. The rate of decrease is approximately equal to that observed in corresponding Cu- and Ag-base alloys, apparently showing that for these alloys a simple separation of valence and ionic effects may be made.

Invited Papers

Q8. High-Frequency Nuclear Magnetic Resonance in Antiferromagnetics. V. JACCARINO, *Bell Telephone Laboratories.* (30 min.)

Q9. Cyclotron Resonance in Metals. A. F. KIP, *University of California, Berkeley.* (30 min.)

FRIDAY AFTERNOON AT 2:45

Panel Room

(W. K. H. PANOFSKY presiding)

Invited Papers

QA1. Structure in the Neutron and Proton. R. HOFSTADTER, *Stanford University.* (30 min.)

QA2. Large-Angle Electron-Pair Production from Hydrogen. B. RICHTER, *Stanford University.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Terrace Room

(V. L. STOUT presiding)

Electron Physics

R1. Electroluminescence of ZnS Single Crystals under Pulsed Voltage Excitation. D. R. FRANKL, G. NEUMARK, AND A. LEMPICKI, *Sylvania Electric Products.*—On application of voltage to a previously de-excited crystal, the emission intensity rises montonically to a steady level that is a rapidly increasing function of the voltage magnitude. On removal of the voltage, the emission from Mn-activated crystals simply decays to zero, but Cu-activated crystals give a large burst of emission that reaches maximum intensity in a few tens of microseconds then decays in a few milliseconds. Reapplication of voltage during the initial stages of this burst gives strong quenching if the field is in the initial direction, but strong stimulation if in the opposite direction. These effects are explained in terms of excitation in the strong fields existing in barriers, and the assumption that ionized Cu centers have capture cross section that is small for the fast electrons which penetrate the barriers, but large for slow electrons which flow back into the space charge region on removal of the voltage

R2. Mean Lifetime of Free Electrons in Electroluminescent Zinc Sulfide. WILLI LEHMANN, *Westinghouse Electric Corporation.*—The mean lifetime of free electrons in the conduction band of electroluminescent zinc sulfide phosphors has been estimated from measurements of the number of emited light quanta and of the electrical power absorption. The result at room temperature for the mean lifetime of a free electron between excitation and recombination, but not counting the trapping time, is in the order of 10^{-9} sec. This value is fairly independent of amplitude and frequency of the exciting electric

field and is about the same for several phosphors of different emission color (blue ZnS-Cu, green ZnS-Cu,Cl, and yellow ZnS-Mn,Cu).

R3. Electron Transitions in the Activator Center of Magnesium Fluorogermanate. C. H. HAAKE AND G. KEMENY, *Westinghouse Electric Corporation.*—Magnesium fluorogermanate activated with Mn is a red-emitting phosphor used for color correction in high-pressure mercury-vapor lamps. Little is known about the nature of the electron transitions in the activator center (Mn^{4+}). An attempt is made to interpret the relationship of emission intensity and temperature on the basis of the energy term scheme observed in isolated Mn^{4+}. The transitions are of the type ${}^4F_{9/2} \rightleftarrows {}^2G_{9/2}$. The effect of crystal fields on the term scheme of Mn^{4+} seems to be small. Upon application of the selection rules[1] $\Delta L = \pm 1$, $\Delta J = 0$, $\Delta S = \pm 1$, it becomes apparent that electron transitions take place only between ${}^4F_{9/2} \rightleftarrows {}^2G_{9/2}$ and ${}^4F_{7/2} \rightleftarrows {}^2G_{7/2}$ whereas the two lower ground states ${}^4F_{3/2,\,5/2}$ do not contribute to absorption and emission. The occupancy of the four ground states is governed by Boltzmann statistics. Hence, with increasing temperature the probability of finding centers in the upper two ground states increases and so does the absorption. The increase of emission intensity up to 300°C can thus be explained. Further temperature increase leads to a predominance of nonradiative transitions over radiative transitions and the emission intensity decreases.

[1] B. V. Thosar, Phil. Mag. **26**, 380 (1938).

R4. Photoelectric Emission from MgO.* JAMES R. STEVENSON† AND EUGENE B. HENSLEY, *University of Missouri.*—Measurements of the photoelectric yield from thin films, powders, and single crystals of MgO have been made as a function of photon energy from 2.5 ev to 11.5 ev. The yield below 7.5 ev was observed to be structure sensitive. On the more active samples, this yield could be detected as low as about 3.0 ev with a minimum detectable quantum efficiency of about 10^{-10} electron per quantum and increased with some suggestion of structure to about 10^{-4} at 7.5 ev. The yield at the lowest energies could be enhanced by irradiating at higher energies. The shape of the curve for the efficiency of the enhancing radiation was observed to coincide with a photoconductivity peak centered at 5 ev obtained by Peria[1] and confirms Peria's identification of this photoconductivity as being due to the release of electrons to the conduction band. A sharp rise in yield by as much as two orders of magnitude at 7.5 ev in the most active samples coincides with the exciton induced optical absorption. This rise could be greatly reduced by heating the sample in oxygen. This treatment had no effect on the yield at energies greater than 10 ev.

* Supported in part by the Office of Naval Research.
† Now at Georgia Institute of Technology.
[1] W. T. Peria, Ph.D. thesis, University of British Columbia, 1957.

R5. Thermionic Emission and Electronic Structure of MgO.* EUGENE B. HENSLEY AND JAMES R. STEVENSON,† *University of Missouri.*—Measurements of the thermionic emission from powders, single crystals, and thin films of MgO have been made as a function of temperature. Analysis of the temperature dependence of the work function obtained from these measurements and from measurements reported in the literature indicate that the position of the Fermi level in most samples of MgO is controlled primarily by the population of a donor level located approximately 3.4 ev below the vacuum level. The following details regarding a tentative energy level diagram for MgO will be discussed. The electron affinity is estimated to be somewhat less than 1 ev. The 2.4-ev peak in the optical absorption is probably due to the same center as the donor discussed above and is also probably responsible for the low-energy photoelectric emission. A second level slightly greater than 5 ev below the conduction band is suggested by photoconductivity and the enhancement of the photoelectric emission discussed in the previous paper. Indications of the width of the forbidden band are vague but a value near 8.8 ev is strongly indicated. The exciton absorption peaks at 7.5 ev with a second possible peak at 8.8 ev.

* Supported in part by the Office of Naval Research.
† Now at Georgia Institute of Technology.

R6. Secondary Electron Emission Variation with Incident Angle. A. B. LAPONSKY AND N. R. WHETTEN, *General Electric Research Laboratory.*—The dependence of secondary electron emission on angle of incidence of the primary electrons has been measured for cleaved single crystals of MgO. Single pulse measurement techniques have been employed.[1] The energy distribution of the secondary electrons has been measured at different incident angles and primary energies. At low primary energies there is little change in the energy distribution with different angles of incidence. At primary electron energies near the maximum in the yield curve the secondary electron energy distribution is found to vary with the incident angle. Relatively more high-energy secondary electrons are present at large incident angles than at normal incidence. At considerably higher primary energies there is again little change in energy distribution with angle of incidence. The total secondary electron yield is found to exhibit maxima at several angles of incidence. The position of these maxima are independent of primary electron energy and are believed to be associated with crystal orientation.

[1] N. R. Whetten and A. B. Laponsky, Phys. Rev. **107**, 1521 (1957).

R7. Exciton-Induced Photoemission from BaO at 80°K. E. TAFT AND L. APKER, *General Electric Research Laboratory.*—Zollweg[1] has found four peaks near $h\nu = 4$ ev in the optical absorption spectrum of BaO. Jahoda[2] has seen the same structure in reflectivity studies. The present experiments show that when sufficiently shallow electron donor states are introduced into BaO, these peaks appear clearly at 80°K in the spectral distribution of the photoelectric yield. The effect appears similar in character to the exciton-induced photoemission from alkali halides. In BaO, the phenomenon is particularly interesting as a sensitive means for studying the relatively weak low-energy peak found by Zollweg and Jahoda near 3.7 ev. Photoemission associated with this peak is frequently measurable even at 3.3 ev, and it is probably the source of the unexpected slow electrons in energy distributions studied by Philipp.[3] Electron donor states only 0.8 ev below the vacuum level were seen during the present studies.

[1] R. J. Zollweg, Phys. Rev. **97**, 288 (1955); Bull. Am. Phys. Soc. Ser. II, **2**, 342 (1957).
[2] F. C. Jahoda, Phys. Rev. **107**, 1261 (1957).
[3] H. R. Philipp, Phys. Rev. **107**, 687 (1957).

R8. Mass-Spectrometer Measurements of Oxygen Adsorption and Desorption on Tungsten.* R. E. SCHLIER, *Brown University.*—The adsorption of oxygen, nitrogen, and carbon monoxide on a tungsten flash filament mounted on tungsten supports was measured with an omegatron rf mass spectrometer. Comparable results were obtained with an ionization gauge, for nitrogen and carbon monoxide, but not for oxygen. The tungsten filament adsorbed 1.1×10^{15} atoms/cm^2 of oxygen, with an initial sticking coefficient of 0.5. When the filament was flashed at 2000°K, a small oxygen pressure rise indicated that less than two percent of the oxygen desorbed as oxygen molecules. A larger pressure rise due to carbon monoxide also occurred because this gas was present whenever the omegatron filament was heated in oxygen. The oxygen

was removed from the surface by flashing, probably as a volatile oxide. At elevated temperatures, the tungsten filament pumped oxygen. Some of the oxygen was converted into carbon oxides in insufficient quantities to account for the pumping. At 1850°K, the pumping speed of the filament for oxygen was about 8 liters/sec/cm². The pumping of oxygen and conversion into carbon oxides account in part for the unreliability of the ionization gauge as an oxygen pressure indicator.

* This work is supported by a Joint Services Contract with MIT and a subcontract with Brown University, and by a contract with Air Force Cambridge Research Center, Air Research and Development Command.

R9. Surface Migration of Carbon Monoxide on Tungsten.* RALPH KLEIN, *National Bureau of Standards.*—The surface migration of carbon monoxide on tungsten was observed with the field emission microscope. The field emission tube was operated in liquid helium.[1] Carbon monoxide, generated by heating molybdenum carbonyl, shadowed a tungsten point. The migration process could be observed because adsorbed carbon monoxide causes a slight increase in the work function of tungsten. The migration commenced at a conveniently measurable rate in the vicinity of 180°K, the process being characterized by an activation energy in the region of 5 kcal. The detailed observations on the characteristics of the migration as revealed by the emission patterns will be discussed.

* This research was performed under the National Bureau of Standards Free Radicals Program supported by the Department of the Army.
[1] Gomer, Wortman, and Lundy, J. Chem. Phys. **26**, 1147 (1957).

R10. Resolving Power of Electron Spectrometers.* L. MARTON, *National Bureau of Standards.*—It is customary to express the performance of an electron spectrometer by plotting the resolving power $\Delta p/p$ *vs* transmission T (where T is the fraction of 4π solid angle and p is the momentum). An examination of the literature indicates that a purely empirical relationship can be established for the limiting performance of these instruments; i.e., all the recorded performances are above the curve $T=3(\Delta p/p)^{3/2}$. Such a limiting curve suggests a natural limitation of some sort and raises the question about the theoretical limits of electron spectrometers. An estimate of the quantum-mechanical limitations of the resolution can be made based on the Heisenberg uncertainty relation. This estimate is several orders of magnitudes better than the observed performances. Part of the discrepancy may be in the fact that, in almost all resolving power measurements, the true value is masked by the thermal distribution of electron energies. Thus it should be possible to achieve truly high resolution electron spectroscopy by the utilization of more monoenergetic sources of electrons.

* This work was in part supported by the U. S. Atomic Energy Commission.

R11. Modulated Retarding Field "Monochromator" for Electron Scattering Measurements.* J. AROL SIMPSON, *National Bureau of Standards.*—The resolution of modern electron velocity analyzers appears to be limited by the initial energy spread of the primary beam. Improved resolution requires some form of monochromator. Fox and Hickam[1] have reduced the apparent line width of an electron beam by use of a modulated retarding field system. The performance of such a device depends on the sharpness of the low-energy cutoff of the retarding field. Boersch[2] has done considerable work on this problem in connection with his filter lenses. By combining such a filter lens with a modulating system it appears possible to obtain electron beams with an apparent energy spread of less than 0.1 ev at an energy of 20 to 50 kev. If this "monochromator" is combined with modulated retarding field analyzer described by Leder and Simpson,[3] a particularly compact and convenient instrument results.

* This work was in part supported by the U. S. Atomic Energy Commission.
[1] Fox, Hickam, Grove, and Kjeldaas, Rev. Sci. Instr. **26**, 1101 (1955).
[2] H. Boersch, Optik **5**, 436 (1949).
[3] L. B. Leder and J. A. Simpson, following abstract.

R12. Differentiation of Retarding Potential Measurements.* LEWIS B. LEDER AND J. A. SIMPSON, *National Bureau of Standards.*—The measurement of electron energy by the retarding potential method is attractive from the standpoint of simplicity of design and also because the resolution is not a function of the primary electron energy or the physical size of the instrument. Its biggest drawback has been the fact that an integral rather than a differential curve of energy *versus* current is obtained. Graphical differentiation introduces a rather large error, particularly in the regions of large slope. To overcome this difficulty we have improved some early attempts at electrical differentiation.[1,2] A 1000-cy signal of approximately 0.1 ev is superimposed on the retarding potential. The resulting output signal is an amplitude modulated ac current which is amplified and passed through a lockin circuit which improves the signal-to-noise ratio. The differential energy distribution is thus obtained directly. A half-width of 0.6 ev at a primary energy of 5000 v has been obtained.

* This work was in part supported by the U. S. Atomic Energy Commission.
[1] P. Vetterlein, Ann. Physik **35**, 251 (1939).
[2] N. B. Gornii and L. M. Rachovich, J. Exptl. Theoret. Phys. **26**, 454 (1954).

R13. Bremsstrahlung from Electrons in a Fully Ionized Gas Using the Debye Potential. HUGH E. DEWITT AND RAY E. KIDDER, *University of California, Livermore.*—An electron moving through a fully ionized gas feels an average potential in the neighborhood of a heavy ion of the form $V(r)=Ze^2/r \times\exp(-r/a)$ where $a=(kT/4\pi Ne^2)^{\frac{1}{2}}$ is the Debye screening length. We have calculated in Born approximation the total bremsstrahlung cross section for an electron incident on this potential. Using this cross section we have obtained the rate of electron energy transfer to the radiation field. This result consists of the usual energy loss rate for a pure Coulomb potential multiplied by $(1-a\tan^{-1}a)$ with $a=\hbar/2p_0a$ and p_0 the initial electron momentum. The screening effect vanishes at sufficiently high temperatures. A high electron density can materially reduce the energy loss by bremsstrahlung. Using the bremsstrahlung energy loss rate for one electron, calculations were made to estimate the average rate of transfer of energy from electrons with a Maxwellian velocity distribution in the gas to the radiation field.

R14. Shielded Coulomb Encounters in a Fully Ionized Gas Using the Debye Potential. R. E. KIDDER AND H. E. DEWITT, *University of California, Livermore.*—Calculations have been made of the rate at which energy is transferred from electrons at a temperature (T) to cooler ions (taken to be at rest) in a fully ionized gas. The form of the interaction between ion and electron is assumed to be of the Debye form $(Ze^2/r)\exp(-r/a)$ where a is the Debye shielding length. The calculations are made in Born approximation. In the usual treatments of energy transfer the interaction between the charged particles is taken to be the Coulomb interaction, and integration over the impact parameter is cut off at some maximum value. This maximum value is taken equal to the Debye length, or a modification thereof to account for quantum effects. The present treatment systematically employs the Debye potential and has the advantage that it is not necessary to introduce the somewhat arbitrary cutoff. The expression that is obtained for the rate of energy transfer contains a term not obtained in the cutoff method. This term has the effect of reducing the energy transfer rate.

FRIDAY AFTERNOON AT 2:00

Boston-Washington Room

(K. M. WATSON presiding)

Theoretical Physics IV: Nuclear Structure

S1. Photodisintegration of the Deuteron at 22 and 78 Mev.* J. J. DE SWART, D. E. BILHORN, AND R. E. MARSHAK, *University of Rochester.*—We have calculated the photodisintegration of the deuteron at γ-ray energies of 22 and 78 Mev using the Gartenhaus wave function for the deuteron and the Gartenhaus plus spin-orbit wave functions[1] for the final states. The dominant transition is electric dipole—namely, ${}^3S_1+{}^3D_1\rightarrow{}^3P_{0,1,2}, {}^3F_2$. If we write the differential cross section in the form $(a+b\sin^2\theta)$, then we find $a=4.1$ μb, $b=50$ μb, at 22 Mev and $a=4.1$ μb, $b=4.3$ μb at 78 Mev. This is in good agreement with experiment. This result indicates that it is not necessary to introduce virtual pion or other effects[2] in order to explain the large isotropic term in the angular distribution in this energy region. The extent to which the large percentage of D state for the deuteron and the effect of the spin-orbit force on the final states contribute to the satisfactory result will be discussed.

* Supported in part by IBM.
[1] P. S. Signell and R. E. Marshak, Phys. Rev. **106**, 832 (1957).
[2] R. R. Wilson, Phys. Rev. **104**, 218 (1956); also N. Austern, University of Pittsburgh preprint.

S2. Nuclear Saturation. W. W. WADA AND P. P. BEY, *U. S. Naval Research Laboratory.*—Brueckner many-body theory has been applied to nuclear matter, assuming that the single-particle velocity-dependent potential can be parametrized in the form $\frac{1}{2}(ck^2-b)/(1+ak^2)$. This potential goes over to that of the effective mass approxination in the low momentum region and becomes constant ($\frac{1}{2}c/a<1$) for high momenta, in agreement with the requirement that the effective mass should approach the real mass of the nucleon when off-the-energy shell effects are disregarded. These parameters are determined by the self-consistency requirement of the theory. The resulting Schrödinger equation can be solved analytically for an attractive square well with repulsive hard core. The method of Riesenfeld and Watson results in a reaction matrix proportional to the phase shift when the exclusion effects in the intermediate states are disregarded. Assuming that the s orbital alone is sufficient, the two-body potential used is that which is an appropriate average between the triplet and singlet interactions. The self-consistent solutions of the Brueckner integral equation have been obtained at several densities. Saturation of nuclear matter occurs at the normal density corresponding to a nuclear radius $=1.4\times10^{-13}$ A$^{\frac{1}{3}}$ cm, with approximately -15 Mev for the binding energy per nucleon. The exclusion effects were treated by Schwinger's variational method, and found to be negligible.

S3. Studies with Velocity-Dependent Potentials.* P. C. SOOD AND A. E. S. GREEN, *Florida State University.*—A study is made of the influence upon energy eigenvalues of the extra terms associated with a Hermitian symmetrized kinetic energy operator, a Hermitian nonsymmetrized operator as contrasted with a simple non-Hermitian nonsymmetrized form. The results indicate that for important states of binding the extra terms do not greatly alter the energy level or level sequences. A number of studies of bound states and positive energy states have indicated the need for an extra nuclear well depth for protons as compared to neutrons. On the other hand a recent study of mirror nuclei[1] does not reveal this potential anomaly. The detailed characteristics of the proton potential anomaly for various nuclei are explored further using a combination of analytical techniques and a table of eigenvalues and eigenvalue derivatives, obtained with the aid of the ORNL Oracle. It is found that the extra well depth needed in medium and heavy nuclei in the velocity dependent case is comparable with that needed in the static case.

* Supported by a grant from the U. S. Atomic Energy Commission.
[1] P. C. Sood and A. E. S. Green, Nuclear Phys. (to be published).

S4. Distribution of Angular Momenta among the Nuclear Levels of Aluminum.* CARL T. HIBDON, *Argonne National Laboratory.*—The density of levels[1] as a function of total angular momentum J is given for the single-particle model by the expression

$$\rho(J)=\rho_t\left[\exp\left\{\frac{-J^2}{2c\tau}\right\}-\exp\left\{\frac{-(J+1)^2}{2c\tau}\right\}\right]$$
$$\approx\rho_t\frac{(2J+1)}{2c\tau}\exp\left\{\frac{-(J+\frac{1}{2})^2}{2c\tau}\right\},$$

where ρ_t is the density of all levels for the energy region in question, τ is the so-called nuclear temperature that varies slowly with energy, and c is a constant having the value $1/75B^2A^{\frac{2}{3}}$ Mev^{-1}. Lang and LeCouteur found the constant B to have a value of 0.55 for a fit to observed level densities and A is the mass number of the nucleus. The numbers of levels assigned experimentally to each different value of J hitherto have been too small to permit verification of the theoretical expression. In the present work, a sufficient number of levels of aluminum have been tentatively identified to give a rough experimental check of the theoretical distribution. A reasonably good fit is given for $2c\tau=6$. The constant c has a value of 1.04 Mev^{-1} so the corresponding value of τ is 2.9 Mev.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. M. B. Lang and K. J. LeCouteur, Proc. Phys. Soc. (London) **A67**, 586 (1954). See also H. Bethe, Revs. Modern Phys. **9**, 69 (1937), formula (301); T. D. Newton, Can. J. Phys. **34**, 804 (1956); and C. Bloch, Phys. Rev. **93**, 1094 (1954).

S5. Relativistic and Coulomb Corrections to Nuclear Fermi Matrix Elements. W. M. MACDONALD, *University of Maryland.*—The nuclear Fermi matrix elements for β decay can be evaluated in the nonrelativistic limit for charge independent nuclear forces. For a transition between $J=0^+, T=1$ nuclear states the result is $\int 1=\int\beta=\sqrt{2}$. For the $0^+\rightarrow0^+$ decays of O^{14} and Cl^{34} the corrections produced by the Coulomb interaction and relativistic terms of order $(v^2/c)^2$ have been calculated on the jj coupling model. In the Coulomb calculations the $T=0$ and $T=2$ impurities from excited states were considered, as well as the dynamic distortion from the mixing of $T=1$ states. The O^{14} ft value is increased by $\sim0.1\%$ while the Cl^{34} ft value is decreased by $\lesssim1\%$. A relativistic correction occurs only for the vector intrraction in a $0^+\rightarrow0^+$ decay and gives an increase in both the O^{14} and Cl^{34} ft values for these decays by 4.1% and 4.2%, respectively. However, this correction will cause the ratio of the ft values to differ from unity by only $\sim0.1\%$.

S6. Statistical Derivation of Nuclear Rotation Energy.* KAILASH KUMAR, *Purdue University* (introduced by R. W. King).—The nucleus is treated as a Fermi gas of protons and neutrons under the constraints of constant angular momen-

tum[1] and constant quadrupole moment. By using the assumption that the effective nuclear potential is of the form of a spheroidal well, the characteristic $I(I+1)$ rotational spectrum is obtained in the first approximation. The moment of inertia thus calculated is half that of the rigid rotation[2] of the nucleus as a whole. An expression closer to that of irrational flow results if one assumes that only the nuclear matter displaced as a result of the deviation from spherical shape contributes to the angular momentum. The effect of introducing a velocity dependent potential is to increase the moment of inertia, but no strong dependence on deformation is obtained. Calculations with an l^2 dependent potential suggest that by combining the last two assumptions a situation close to reality may be obtained.

* Work performed at McGill University.
[1] A. M. Sessler and H. M. Foley, Phys. Rev. **96**, 366 (1954).
[2] Compare B. J. Blin-Stoyle, Nuclear Phys. **2**, 169 (1956); also, e.g., D. R. Inglis, Phys. Rev. **97**, 701 (1955).

S7. Influence of Electromagnetic Spin-Orbit Coupling on C^{14} and O^{14} β Decay.* J. SUCHER AND R. A. FERRELL, *University of Maryland.*—One source of the difference in the *ft* values of C^{14} and O^{14} is the smaller spin-orbit splitting for neutron holes, relative to that for proton holes.[1] The decrease in spin-orbit strength a has been calculated using the known anomalous magnetic moments for proton and neutron. Neglecting exchange, we find $\Delta a \approx -0.075$ Mev. This perturbation increases the O^{14} matrix element, M (measured in multiples of 10^{-2}), by 1.2, to which must be added 1.9 due to the Coulomb repulsion in C^{14} of the proton holes.[2] It is necessary to assume that the C^{14} matrix element, of magnitude 0.8, has the same sign as that for O^{14}. We then find $M=3.9$, which may be compared with the experimental value of 6.3 ± 0.5. Part of the remaining discrepancy may be due to forbidden terms in the O^{14} matrix element, so far neglected.

* Research supported in part by the U. S. Atomic Energy Commission.
[1] W. M. Visscher and R. A. Ferrell, Phys. Rev. **107**, 781 (1957).
[2] B. Jancovici and I. Talmi, Phys. Rev. **95**, 289(L) (1954).

S8. Variational Formulation of the Nuclear Many Body Problem.* R. BROUT, *Cornell University.*—An attempt is made to find the wave function ψ, which variationally gives rise to the Brueckner-Bethe formulation of the nuclear many-body problem. If ψ is written as a sum of two-body correlations, each two-body part involves the scattering matrix G. The total energy may then be written as a sum of pair energies. The uncanceled unlinked clusters lead to weight factors for each pair. If these weight factors are approximated by unity, variation of G leads to integral equations for G and total energy $E=\langle T\rangle+\frac{1}{2}\sum_{mn}\langle mn|G|mn\rangle$, thereby recovering the Brueckner-Bethe form. The integral equation differs from the usual one in two respects: intermediate states include hole scattering (3 body clusters in usual formulation); the energy denominators involve Hartree-Fock energies. For singular potentials one must therefore correct to get finite self energies. This is easily achieved for hole states but no finite modification of ψ leads to unambiguous particle state self-energy. For singular potentials it does not seem possible to construct simple trial wave functions which lead to finite results.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

S9. Collective *E2* Enhancement of Transition Rates and Quadrupole Moments in Some Light Nuclei.* S. FALLIEROS AND R. A. FERRELL, *University of Maryland.*—The strength of interaction between an individual nucleon and a spheroidal deformation of the O^{16} core has been determined empirically from the experimental lifetime measurements[1] on the first excited states of N^{16} and O^{17}. From these data the F^{17} first first excited state can be expected to have a mean lifetime of 5.6×10^{-18} sec. By taking into account the different radial wave functions involved in *s-d* and *d-d* transitions, as well as the radial extension of the "surface" wave and the finite range of nucleon-nucleon forces, the O^{17} quadrupole moment can also be calculated.[2] An analogous treatment can be given to holes in the O^{16} core. Using the same interaction strength we find the N^{14} quadrupole moment is increased 50% above its shell-model value. Similarly, the *E2* decay rate of the N^{14} second excited state[3] is doubled.

* Research supported by the U. S. Atomic Energy Commission.
[1] R. C. Hanna and J. M. Freeman (private communication). J. Thirion and V. L. Telegdi, Phys. Rev. **92**, 1253 (1953).
[2] The result compares reasonably with the recent experimental value of M. J. Stevenson and C. H. Townes [Phys. Rev. **107**, 635 (1957)].
[3] For references to the experimental data on N^{14} see Sec. V of W. M. Visscher and R. A. Ferrell, Phys. Rev. **107**, 781 (1957).

S10. Optical Model Scattering Potential for Elastic Nuclear Scattering.* LEE M. FRANTZ, *The Ohio State University.*—A formal expression has been found for an optical model potential, which provides an exact description of the elastic scattering of a single nucleon from a nucleus. The starting point is the standard second-quantized description of a many-nucleon system in terms of two-body potentials and of a complete set of model wave functions. The variables of all but the bombarding nucleon are eliminated, and it is shown that its weighting function on the state vector's *model* nuclear ground state projection satisfies a single-particle Schroedinger equation allowing the identification of a potential V_{OM}. In addition the elastic component of the scattering of a nucleon from a true nucleus is shown to be given by the scattering of a nucleon by V_{OM}. The potential V_{OM} is complex, and is energy and momentum dependent. It can be expanded in a natural manner in a Brillouin-Wigner type of perturbation series, and an attempt is now in progress to convert a Rayleigh-Schroedinger series with the expectation of eliminating unlinked cluster terms, as in the Brueckner theory.[1]

* Supported by the National Science Foundation.
[1] K. A. Bruckner, Phys. Rev. **100**, 36 (1955).

S11. Theoretical Investigation of First-Forbidden Beta Decays of Sb^{124} and Au^{198}.* M. MORITA AND R. SAITO MORITA, *Columbia University.*—We have calculated the formulas of beta-gamma direction and polarization correlations with STPVA interactions of beta decay. Using these formulas, a consistent explanation has been given for all of the data of the first-forbidden beta decays on Sb^{124} and Au^{198}. We can explain the beta-spectrum shapes, ft values, beta-gamma direction, and polarization correlations on Sb^{124} and Au^{198}. We can also account for the beta polarization experiments on Au^{198}. For both nuclei, STP with $C_i=C_i'$ predicts the same results as the VA with $C_i=C_i'$. In the case of Au^{198}, it is necessary that the interference among STP or VA or both be maximum and that B_{ij}^{β} and B_{ij} be very small. All of the data on Au^{198} are consistent with the assumption of real coupling constants. In the case of Sb^{124}, large B_{ij}^{β} and B_{ij} terms are necessary. Then, the reality of the coupling constants is indeterminate from the data of Sb^{124}.

* This work was partially supported by the U. S. Atomic Energy Commission.

S12. Photonuclear Giant Dipole Resonance in O^{16}.* RICHARD A. FERRELL, *University of Maryland.*—Both Brink[1] and Wilkinson[1] have discussed the giant dipole resonance in terms of single-nucleon excitations. Brink has made the important observation that the wave function describing a collective Goldhaber-Teller excitation is simply a superposition of a single-nucleon excitations. He fails, however, to note that there is a shift in the energy of this superposition which separates it from the lower-lying set of single-nucleon excitation energies. Corresponding energy shifts have been

discussed for the breathing (EO) and spheroidal ($E2$) modes of oscillation.[2] Because of the shift there are no other single-nucleon shell-model excitations in the vicinity of the collective dipole excitation. Thus the resonance would be sharp, except for unrelated damping mechanisms. Insofar as the central force dominates the spin-orbit force the line-breadth is not due to a distribution of the resonance over single-nucleon excitations, in contrast to the theories of Brink and of Wilkinson.

* Research supported by the U. S. Atomic Energy Commission.
[1] D. M. Brink, Nuclear Phys. 4, 215 (1957). D. H. Wilkinson, Physica 22, 1039 (1956).
[2] R. A. Ferrell and W. M. Visscher, Phys. Rev. 102, 450 (1956); 104, 475 (1956). R. A. Ferrell, Phys. Rev. 107, 1631 (1957).

S13. Inelastic Scattering of Pions by Nuclei. K. M. WATSON AND C. ZEMACH, *University of California, Berkeley.*—Monte Carlo calculations of the scattering of pions within nuclei have not led to very good agreement with the observed energy spectrum of the scattered mesons.[1] These studies have assumed the scattering of pions on free neutrons and protons as the elementary mechanism for scattering within nuclei. It is expected, however, that the "optical model" potential for pions is strong and also quite energy-dependent, which can lead to an appreciable change in the kinematics of pion-nucleon collisions within nuclei. This change is in at least qualitative agreement with observation.

[1] R. H. Miller (preprint).

FRIDAY AFTERNOON AT 2:00

Grand Ballroom

(R. W. HAYWARD presiding)

Form Factors; Proton Scattering; Polarization and Parity; Recoil Experiments

SA1. Study of the Magnetic Form Factor of the Neutron at 600 Mev.* M. R. YEARIAN AND R. HOFSTADTER, *Stanford University.*—Further experimental investigation of the neutron's magnetic form factor has been continued[1] at 600 Mev. The deuteron electrodisintegration data can be compared with theories of Jankus[2] and Blankenbecler[3] with inclusion of the proton and neutron form factors. When the form factors are included, the theoretical shape of the inelastic continuum changes with respect to the original theoretical shape calculated by Jankus for points. The present results at 600 Mev are compared with a model which fits the 500-Mev data. From these results, the neutron's magnetic cloud is definitely not a point and is of approximately the same size as the proton magnetic cloud. Possible differences between the neutron and proton will be discussed.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and by the Office of Scientific Research, Air Research and Development Command.
[1] M. R. Yearian and R. Hofstadter, Bull. Am. Phys. Soc. Ser. II, 2, 389 (1957).
[2] V. Z. Jankus, Phys. Rev. 102, 1586 (1956).
[3] R. Blankenbecler (to be published).

SA2. Investigation of the Charge Form Factor of the Proton.* F. BUMILLER AND R. HOFSTADTER, *Stanford University.*—An examination of the proton's charge structure function[1] (=Dirac form factor, F_1) has been carried out by scattering electrons from protons in CH_2 at electron energies 200 Mev and 600 Mev in the laboratory system. The method takes advantage of the fact that at small scattering angles the ratio of cross sections ($\sigma_{200}/\sigma_{600}$) is sensitive to F_1 and practically independent of the magnetic form factor F_2. Thus very little knowledge of the magnetic form factor is required to determine precise features of the F_1 distribution. When the results are, for convenience, put in the form of a phenomenological charge-density distribution, the exponential model with rms radius 0.80×10^{-13} cm, gives a good fit. This result indicates that the electrical size of the proton is the same as the magnetic size,[2] at the momentum-transfer values presently investigated. The data can also be presented equivalently, without referring to a model, in the form of phenomenological structure functions.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and by the Office of Scientific Research, Air Research and Development Command.
[1] R. Hofstadter, Revs. Modern Phys. 28, 214 (1956).
[2] F. Bumiller and R. Hofstadter, Bull. Am. Phys. Soc. Ser. II, 2, 390 (1957).

SA3. Proton-Proton Scattering at 10 Mev.* LAWRENCE H. JOHNSTON AND DONALD E. YOUNG, *University of Minnesota.*—The angular distribution of proton-proton scattering cross sections at 9.74 Mev has been measured using the first section of the Minnesota Proton Linear Accelerator and the small-angle scattering chamber previously described.[1] The scatterer is hydrogen gas at one-quarter atmosphere pressure which flows continuously through the chamber. Measurements have been made from 5° to 55° (lab) with $\pm\frac{1}{2}°$ resolution from 5° to 20° and $\pm2°$ from 20° to 55°. The absolute angular setting of the detector telescope at 5° has been confirmed by doing Rutherford scattering from argon gas which agrees to within $\frac{1}{2}\%$. The errors have been estimated to be $\pm\frac{1}{2}\%$ relative and $\pm1\%$ absolute. The cross-section curve shows an interference minimum at 17° (lab.) which is about 4% below the 45° value. The shape of the curve near the minimum has been investigated carefully and shows a much narrower "dip" than would be predicted by pure S-wave scattering. A phase-shift analysis is being made.

* Supported in part by the U. S. Atomic Energy Commission.
[1] D. A. Swenson and L. H. Johnston, Bull. Am. Phys. Soc. Ser. II, 2, 180 (1957).

SA4. Elastic Scattering of 40-Mev Protons.* MORTON K. BRUSSEL† AND JOHN H. WILLIAMS, *University of Minnesota.*—Forty-Mev protons from the University of Minnesota linear accelerator were elastically scattered from Fe^{54}, Fe^{56}, Ni^{58}, Ni^{60}, and Cu^{65} targets to obtain absolute differential cross sections in the range of laboratory angles 7.5° to 110°. Measurements were made using NaI (Tl) scintillation detectors which could in general distinguish between elastic and inelastically scattered protons. Differential cross sections varied from a maximum at 7.5° to a minimum approximately four orders less in magnitude at 110°. Generally, the cross sections followed a point charge Coulomb law variation, departing therefrom only at diffraction-like maxima and minima. Maxima appeared near 36.5°, 62.5°, and 95°. Minima appeared near 27°, 55°, and 85°, and an inflection was noted at approximately 14°. Distinct differences in the features of the angular distributions from element to element were noted. A discussion of the effects probably due to closure of the $Z=28$ and $N=28$ shells will be given.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at Brookhaven National Laboratory.

SA5. Proton-Proton and π^+ Meson-Proton Elastic Scattering at 1.23 Bev/c. LEONARD O. ROELLIG AND DONALD A. GLASER, *University of Michigan.*—A beam of positive particles from the Brookhaven Cosmotron, magnetically focused and analyzed, was sent through a 12-in. propane bubble chamber. The ratio of the number of protons to the number of pions, muons, and electrons in the beam was 1.75±0.09. The differential and total cross sections for p-p elastic scattering agree with results of counter experiments performed at a similar energy. We find that the π^+-p differential elastic scattering has the same shape as has been observed for π^--p elastic scattering in this energy region. Curves and values of the cross sections will be presented.

SA6. Scattering of μ^- Mesons by Nuclei. J. FRANKLIN AND B. MARGOLIS, *Columbia University.*—Determination of the direction of the spin of μ mesons from π-meson decay is of interest in weak interaction theory. The longitudinal polarization of the μ mesons from π decay can be converted into transverse polarization by several methods. The scattering of transversely polarized μ^- mesons by point nuclei would have the same left-right asymmetry (for the same β) as calculated by Sherman[1] for electrons. In the energy range (β=0.2−0.9) at which strong polarization effects occur, electrons do not penetrate the nucleus. Mu mesons, however, because of their greater mass, do penetrate and their scattering should be corrected for finite size. A hand calculation has been made for the case Z=80, β=0.2 assuming a uniformly charged nucleus of radius $R=1.2\ A^{\frac{1}{3}}\times10^{-13}$ cm and appreciable left-right asymmetry has been found at large angles (−5% at 105°, −11% at 120°, −20% at 135°). The cross section at these angles varies from 57% of the point nucleus cross section at 105° to 18% at 135°. The indication is that penetration of the nucleus does not destroy the asymmetry predicted by Sherman[1] for point nuclei. This is expected to hold true for higher energies. Machine calculations are being performed for higher energies and further results will be presented at the meeting.

[1] N. Sherman, Phys. Rev. 103, 1601 (1956).

SA7. Polarization of μ^+ from the $K_{\mu 2}$.* JULIET LEE, G. HARRIS, AND J. OREAR, *Columbia University.*—An experiment is in progress to measure the polarization of the μ^+ secondary from $K_{\mu 2}{}^+$ endings in nuclear emulsion. A stack of 3.2×3.5×9.5 inches was exposed to a 300 Mev/c Bevatron K^+ beam with the 9.5-inch dimension vertical. About 28 000 K^+ were stopped in a 1 cm vertical region at the lower end of the stack. Muon secondaries from the $K_{\mu 2}$ will stop at the upper end of the stack which is area scanned under low magnification for μ^+ endings. A solenoid producing 10 000 gauss in the vertical direction was fitted over this end of the stack to reduce the depolarization by the emulsion.[1] Background muons are eliminated by the use of angular criteria after tracing back at least 3 cm. As a check, 7 muons were chosen to be traced back all the way. All 7 tracks led to K^+ endings. So far 58 events have been found which yield a preliminary value $a=+0.17\pm0.23$ for the asymmetry parameter of the μ-e decay. Since the error quoted is the statistical standard deviation, our result is not inconsistent with the Berkeley result using electronic techniques.[2] If the μ^+ polarization is to be the same as in π^+ decay, we would expect to obtain $a=-0.25$ in the limit of large N.[1]

* Supported by the Office of Naval Research, the U. S. Atomic Energy Commission, and the National Science Foundation.
[1] Orear, Harris, and Bierman, Phys. Rev. 107, 322 (1957).
[2] Coombes, Cork, Galbraith, Lambertson, and Wenzel, UCRL-8003 (unpublished).

SA8. Depolarization of Positive Muons in Gases; Search for Muonium.* V. W. HUGHES, A. LURIO, AND D. P. MALONE, *Yale University*, L. LEDERMAN AND M. WEINRICH, *Columbia University.*—The depolarization of positive muons stopped in various gases has been studied in an experiment similar to that of Garwin, Lederman, and Weinrich. The gases at pressures from 20 to 60 atmos were contained in a thin-walled stainless steel cylinder 12 in. in length and 6 in. in diameter. The peak and valley gated positron counting rates were measured at the appropriate values of the magnetic field which causes the precession of the muon spins. The fraction of the total counts which arises from muons stopping in the gas is between about ⅓ and ½. The following values are obtained for the ratios of peak counts (P) to valley counts (V):

Gas and cylinder	Pressure (psi)	P/V
Cylinder alone	···	1.79±0.09
A	825	1.25±0.05
SF_6	300	1.49±0.06
SF_6+Xe	300(Xe-2)	1.54±0.09
SF_6+NO	225(NO-90)	1.38±0.18
N_2O	700–800	1.04±0.04
CO_2	700	1.43±0.15
O_2	900	1.35±0.14

* This research was supported in part by the U. S. Air Force Office of Scientific Research, the Office of Naval Research, and the U. S. Atomic Energy Commission.

SA9. Transverse Polarization of the Electrons in the Decay of Au^{198}.* P. C. SIMMS† AND R. M. STEFFEN, *Purdue University.*—It was suggested by Curtis and Lewis[1] that experiments on the correlation of the transverse polarization of electrons with the direction of a gamma ray would lead to an independent verification of the violation of parity and charge conjugation invariance, and also to a possible test of the invariance under time reversal. Such experiments are being performed on Au^{198}. The transverse polarization of the electrons is observed by elastic scattering on a 2 mg/cm² gold foil (Mott scattering). Control measurements are made by replacing the gold foil with a 4 mg/cm² Al foil. The measurements indicate that the transverse polarization is small: $P_{\parallel}=0.02\pm0.02$; $P_{\perp}=0.04\pm0.04$, where $P_{\parallel}$ indicates the magnitude of the polarization *in* the plane of the electron and gamma ray, and $P_{\perp}$ is the polarization perpendicular to that plane. The measurements are being continued and more accurate data will be presented.

* Supported by the U. S. Atomic Energy Commission and by Eastman Kodak Company.
† Eastman Kodak Fellow.
[1] R. B. Curtis and R. R. Lewis, Phys. Rev. 107, 543 (1957).

SA10. Measurements on the Longitudinal Polarization of Beta Rays from P^{32}, Y^{90}, Au^{198}, and Bi^{210} (RaE). J. S. GEIGER, G. T. EWAN, R. L. GRAHAM, AND D. R. MACKENZIE, *Chalk River Laboratories.*—The polarization of beta rays has been examined using the Moller scattering technique.[1] In our apparatus a ±4° beam of electrons strikes a magnetized Deltamax foil (2.7 mg/cm²). Coincidences are observed between the elastically scattered electron pairs by two scintillation counters symmetrically placed at 37.5° to the incident beam direction and biased to record electron energies greater than 150 kev. To minimize systematic errors the following steps were taken: (a) the apparatus was aligned using optical techniques; (b) the apparatus was evacuated; (c) a low magnetizing field of 0.4 gauss (B in foil=12 860±300 gauss) was used to reduce magnetic deflection of the electrons. The true coincidence counting rates for the two directions of foil magnetization were corrected for the observed true rate with the foil absent (~4%) and, in the case of Au^{198}, for the beta-gamma coincidence rate with the foil present (~6%). The measured asymmetries (difference/average) to date are P^{32} 5.1±0.3%, Y^{90} 4.7±0.3%, Au^{198} 5.0±0.9%, and RaE 3.5±0.8%. The predicted asymmetry for full negative v/c polarization in our geometry is 5.15 to 5.35% depending on spectral shape. The asymmetry with a 4 mg/cm² copper scattering foil under these conditions is <0.1%. No allowance

has been made for source thickness or multiple scattering in the foil.

[1] H. Frauenfelder *et al.*, Phys. Rev. **107**, 643 (1957).

SA11. Polarization of Electrons Emitted in the Decay of Cs^{137} and Pm^{147}.* J. S. GREENBERG, V. W. HUGHES, D. P. MALONE, AND A. R. QUINTON, *Yale University*.—The longitudinal polarization of beta rays emitted in the decay of Cs^{137} and Pm^{147} has been investigated by using a 90° electrostatic analyzer to transform the longitudinal polarization of the electrons into a transverse one and measuring the "left-right" asymmetry in "Mott scattering."[1] The scattered electrons were counted at an average angle of 70° to the beam direction by two scintillation counters placed opposite in azimuth. The beam was monitored by a third counter. Only electrons in the elastic peak (energy corresponding to $v/c=0.6$) were accepted, as was determined by a multichannel pulse-height analyzer. It was found that in general the measured asymmetry was strongly dependent on the analyzing scatterer thickness, emphasizing the importance of plural scattering. Gold evaporated onto a Formvar backing ($<10\mu g/cm^2$) was used for the scatterer, and the thickness of the gold was varied from 75 $\mu g/cm^2$ up to approximately 1 mg/cm^2. The inherent geometrical asymmetries in the apparatus were eliminated by studying the asymmetry as a function of Z of the scatterer. In addition to Au, Ag, Ni, and Al were used. Results will be reported with particular consideration to the possible systematic errors indicated above.

* Supported in part by the Office of Naval Research.
[1] H. A. Tolhoek, Revs. Modern Phys. **28**, 277 (1956).

SA12. Asymmetry of Neutrons from the Capture of Polarized Negative Muons.* C. T. COFFIN, A. M. SACHS, AND D. H. TYCKO, *Columbia University*.—Lee and Yang have suggested that the measurement of the angular distribution of neutrons emitted after the capture of polarized negative muons in complex nuclei may determine the nature of the coupling in the process $\mu^-+p\rightarrow n+\nu$. We have detected the neutrons and decay electrons from several nuclei and have investigated their spacial asymmetry by precessing the stopped muons. Pulse-height analysis of recoil proton energies in a large scintillator is used to determine the approximate neutron energy. No statistically significant neutron asymmetry has been observed from S, Zn, and Pb targets. Measured backward-to-forward ratios, corrected for background and gate-width smearing, for neutrons with proton recoil energy greater than approximately 2 Mev are 1.00 ± 0.02 in S, 0.99 ± 0.03 in Zn, and 0.99 ± 0.10 in Pb. For electrons, the ratios are 1.07 ± 0.02 in S, 1.11 ± 0.06 in Zn, and 1.10 ± 0.16 in Pb. From the electron ratio, an estimate of $12\pm4\%$ of the polarization at the time of capture in S yields a value of $|a|=0.03\pm0.15$ in an assumed neutron distribution of $1+a\cos\theta$ from the S nucleus.

* This research is supported by the U. S. Atomic Energy Commission and the Office of Naval Research.

SA13. Electron-Neutrino Angular Correlation in the Positron Decays of A^{35} and Ne^{19}.* W. B. HERRMANNSFELDT, P. STAHELIN,† AND J. S. ALLEN, *University of Illinois*.—The electron-neutrino angular correlation coefficients of A^{35} and Ne^{19} have been measured at the University of Illinois cyclotron. A repetition of earlier experimental work[1] gives $+0.77<\lambda<+1.08$ for the correlation coefficient of A^{35}. Using the same experimental conditions the correlation coefficient of Ne^{19} was found to be $-0.08<\lambda<+0.08$, in good agreement with the mean value of all previous experiments.[2] The limits given are the experimental limits determined by a least squares analysis of the data. A^{35} has two low-energy branches of 2% and 5% intensity reported by Kistner *et al.*[3] The limits for A^{35} include the extreme possible limits of $\lambda=\pm1.0$ for these low energy branches. The correlation coefficient of A^{35} indicates that the Fermi part of positron decay must be nearly pure vector. The Ne^{19} result is consistant with either A,V or S,T combinations, and taken together with V in A^{35} indicates that A,V is dominant in positron decay.

* Supported in part by the Office of Naval Research.
† Now at the Swiss Institute of Technology.
[1] Herrmannsfeldt, Maxson, Stähelin, and Allen, Phys. Rev. **107**, 641 (1957).
[2] Maxson, Allen, and Jentschke, Phys. Rev. **97**, 109 (1955); M. L. Good and E. J. Lauer, Phys. Rev. **105**, 213 (1957); W. P. Alford and D. R. Hamilton, Phys. Rev. **105**, 673 (1957).
[3] Kistner, Schwarzschild, and Rustad, Phys. Rev. **104**, 154 (1956).

SA14. Apparent Conflict between Electron-Neutrino Angular Correlations in the Beta Decays of He^6 and A^{35}.* J. S. ALLEN, *University of Illinois*.—When the electron-neutrino angular correlation coefficient for A^{35} as reported by Herrmannsfeldt *et al.* in the preceding abstract is considered with the correlations for the decays of the neutron, He^6 and Ne^{19}, an inconsistency is apparent. The correlation coefficients for the decays of the neutron and Ne^{19} are consistent with either the A,V or S,T combinations. However, the He^6 experiment indicates that the Gamow-Teller part of the beta interaction is tensor whereas the A^{35} results in combination with the Ne^{19} and neutron results indicate that the axial vector is the dominant G.T. interaction. At present, there is no obvious explanation of this discrepancy. In order to check our experimental procedures, we plan to measure the angular correlation in the decay of He^6 with the same apparatus which was used for the Ne^{19} and A^{35} experiments.

* Supported in part by the Office of Naval Research.

FRIDAY EVENING AT 7:00

Terrace Room

(H. D. SMYTH AND V. E. EATON presiding)

Banquet of the American Physical Society and AAPT

After-dinner speakers: J. R. KILLIAN, JR., AND ELMER HUTCHISSON

SATURDAY MORNING AT 9:45

Empire Suite

(T. BERLIN presiding)

Theoretical Physics V: Atomic Structure, Statistical Mechanics

T1. Energy Levels of an Electron in the Field of a Finite Dipole. RICHARD F. WALLIS, *U. S. Naval Research Laboratory,* AND ROBERT HERMAN AND HAROLD WILLIS MILNES, *General Motors Corporation.*—A quantum mechanical investigation has been made of the energy levels of an electron moving in the field of two fixed charges having unit magnitude but opposite signs and having a separation R. The Schrödinger equation for this problem is separable in confocal elliptic coordinates. The evaluation of the energy eigenvalues requires the solution of two simultaneous transcendental equations involving continued fractions. The solutions of these transcendental equations have been worked out for the ten lowest bound states over a range of values of R using the IBM 704 electronic computer at the Technical Center of the General Motors Corporation. The binding energy of the electron decreases monotonically as R decreases for all states considered. For a given state the electronic binding energy is very small for values of R less than the Bohr radius of the corresponding hydrogenic state obtained by letting $R \to \infty$. Applications of the results to color center problems and to electronic impurity state problems in solids will be discussed.

T2. Variational Calculations of the Energy of the 2^3S State of Helium. J. TRAUB* AND H. M. FOLEY, *Columbia University.*—Using a 12 parameter Hylleraas type wave function containing only positive powers, a new calculation has been carried out for the 2^3S state of Helium using the Ritz variational principle. The energy was minimized by a descent method. A nonrelativistic energy of -2.175217 a.u. was reached as compared to the lowest previously published value of -2.175203 a.u. from a 6 parameter function.[1] Calculations of mass polarization, relativistic, and magnetic corrections are nearly completed and will be reported. All calculations were done with an IBM 650 computer. A paper describing these calculations will be published shortly.

* Watson Laboratory Fellow IBM.
[1] A. P. Stone, Proc. Phys. Soc. (London) **A68**, 1152 (1955).

T3. Photoelectric Effect at High Energies. T. ERBER, *Illinois Institute of Technology.*—In recent years there has been a revival of interest in the high-energy behavior of certain scattering amplitudes involving bound electrons.[1] Consider, for example, σ_p, the photoelectric cross section, and σ_{pp} = the cross section of the process: "A photon produces a pair in the field of a "naked" (i.e., without electrons) proton such that the electron member appears in the l-s state and the positron is emitted into the continuum." Using the Dirac wave functions for a hydrogen-like atom as a basis for calculation, it has been possible to confirm a remark of G. E. Brown[2] to the effect that the leading term of σ_p becomes equal to that of σ_{pp} at high energies. After a rearrangement of the traditional sequence of summations and integrations, this leading term may be calculated explicity in a relatively straightforward manner. Detailed formulas will be presented and compared with previous results.[3]

[1] Gell-Mann, Goldberger, and Thirring, Phys. Rev. **95**, 1612 (1954).
[2] G. E. Brown and M. L. Goldberger (1955) (private correspondence).
[3] H. Hall, Phys. Rev. **45**, 620 (1934); Revs. Modern Phys. **8**, 358 (1936).

T4. Polarization of a Degenerate Electron Gas by a Point Charge Impurity.* JOHN J. QUINN AND RICHARD A. FERRELL, *University of Maryland.*—The screening around a fixed positive impurity has been studied as a prototype of such more complicated problems as positron annihilation and electron correlation energy. The usual treatment is significantly improved by replacing the Fermi-Thomas statistical model by the self-consistent Hartree central field. This is especially necessary for calculating the induced electron density at the impurity, since the Fermi-Thomas model yields an infinite value. A perturbation treatment of the Hartree equations is equivalent to using Lindhard's wave number-dependent dielectric constant.[1,2] The use of the Hartree field is also equivalent to summing certain terms in perturbation theory to infinite order, in the manner of Gell-Mann and Brueckner.[3] For high electron density the fractional increase in electron density at a monovalent impurity is $2.96r_s - 1.28r_s^{\frac{1}{2}}$, where r_s is the unit sphere radius in Bohr radii.

* Supported by the U. S. Office of Naval Research.
[1] J. Lindhard, Kgl. Danske Videnskab. Selskab Mat.-fys. Medd. **28**, 8 (1954).
[2] We are informed by M. Dresden that a calculation similar to that reported here is contained in a Ph.D. thesis by R. G. Alsmiller, Jr., University of Kansas, 1957.
[3] M. Gell-Mann and K. A. Brueckner, Phys. Rev. **106**, 364 (1957).

T5. Computation of Asymmetric Rotator Constants from Energy Moments.* PAUL M. PARKER† AND L. CARLTON BROWN, *Ohio State University.*—A procedure has been described[1,2] previously which relates the rotational constants of the rigid asymmetric rotator to experimental data through moments of the energy levels. This procedure in many cases permits the computation of rotational constants with much less effort than is usually met in either numerical approximation to roots of secular equations or perturbation methods. Moments have been calculated based on a more general asymmetric rotator Hamiltonian which includes terms allowing for first order stretching effects. Also, for the rigid rotator Hamiltonian, calculations have been made which are based on the factored form of the secular determinants. The results will be presented and discussed.

* This work was supported in part by a contract between the Office of Scientific Research of the Air Research and Development Command, Baltimore, Maryland, and The Ohio State University Research Foundation.
† General Electric Fellow 1956–1957.
[1] L. C. Brown and P. M. Parker, Phys. Rev. **100**, 1764 (1955).
[2] L. C. Brown and P. M. Parker, J. Chem. Phys. **27**, 1108 (1957).

T6. The Long Time Master Equation of a Dilute Gas. PETER L. AUER AND STEPHEN TAMOR, *General Electric Research Laboratory.*—The methods used by Prigogine and co-workers[1] to treat problems in irreversible statistical mechanics have been applied to the problem of deriving a master equation for the nonuniform dilute gas. Each term of the perturbation series obtained by this method is expanded in powers of the concentration. To the first order in the concentration, we find with the aid of Van Hove's criterion[2] that the Liouville operator for the complete distribution function can be represented as a time independent Markoffian operator. The perturbation series for the operator is summed via an integral equation. Converting the operator equation to an integral equation, we obtain a generalization of the usual master equation for the uniform gas.[3] In addition to the familiar collision operator, we obtain interference terms due to gradients in configuration space. The above treatment provides a master equation which is completely nonlocal. This feature of the theory may be ascribed to the fact that Van Hove's condition becomes valid only for times long compared to natural relaxation times of the system.

[1] I. Prigogine *et al.*, Physica **22**, 621 (1956); **23**, 555, 569, 585 (1957).
[2] L. Van Hove, Physica **21**, 517 (1955).
[3] R. Brout, Physica **22**, 509 (1956).

T7. Transport Equation for a Nonuniform Gas. STEPHEN TAMOR AND PETER L. AUER, *General Electric Research Laboratory.*—To obtain a local and irreversible description of a nonuniform gas, a procedure for smoothing the equations of motion over short times has been developed. Writing the solution of the Liouville equation in the form $\rho(t) = U(t,t_0)\rho(t_0)$, we expand U as a sum of 0, 1, 2, $\cdots n$ body operators in such a way that for short times this becomes a concentration expansion. If the characteristic time for an elementary collision is small compared with the time for observable changes in the system, the binary part of U takes on a simple form for intermediate times. This leads to an equation of the Fokker-Planck type in which the collision operator satisfies a simple integral equation. The operator contains the Boltzmann collision operator plus interference terms, and is closely related to the result of Bogolubov.[1] The final result seems to provide a suitable starting point for the development of hydrodynamics, while the long-time behavior can still be recovered by application of the method of Prigogine.[2]

[1] N. Bogolubov, J. Phys. (U.S.S.R.) **10**, 265 (1946).
[2] R. Brout and I. Prigogine, Physica **22**, 621 (1956).

T8. Theory of Nonlinear Boson Fields.* E. P. GROSS, *Brandeis University.*—We study the Hamiltonian for nonrelativistic interacting bosons (such as helium atoms) written in the formalism of seond quantization. The approach is based on an analysis of exact solutions of the associated classical equations of motion.[1] There is always a solution in which the wave field is spatially uniform; for a purely repulsive potential this is the lowest energy solution. We also find solutions representing large amplitude disturbances which for small amplitudes satisfy the Bogolyubov relation between frequency and wave vector. For a potential with a sufficiently strong attractive part, there is a spatially periodic solution. This is shown to be the appropriate solution for liquid helium. The associated disturbances have phonon character for long wavelength but the spectrum has a band character at short wavelengths. We give a procedure for finding corresponding quantum wave functions. A variety of problems, such as the behavior of the boson fluid in a rotating cylinder, flowing through a pipe. propagating disturbances on a carrier background, is solved by investigating the solutions of the classical fluid with appropriate boundary conditions.

* Supported by Office of Scientific Research.
[1] E. P. Gross, Phys. Rev. **106**, 161 (1957).

T9. Transient Behavior of a Dissipative System. JULIUS L. JACKSON.*—In an earlier paper by this author[1] the response of a dissipative system to an externally applied generalized voltage was calculated. This was done in the spirit of the quantum statistical theory of irreversibility as introduced in the paper "Irreversibility and Generalized Noise" by Callen and Welton.[2] The steady state response of the system was obtained but it was not demonstrated that the system exhibited the correct transient behavior. Indeed, the question of the transient was completely omitted and it was not clear from what was done that the quantum mechanical model of a linear dissipative system was truly linear in the sense of having the correct transient response. Here, a general proof will be given that the dissipative system behaves for all times exactly as a linear system with transfer function, $F(\omega)$, should and therefore must also have the correct transient behavior.

* This research was performed under the National Bureau of Standards Free Radical Research Program, supported by the Department of the Army.
[1] J. L. Jackson, Phys. Rev. **87**, 471 (1952).
[2] H. B. Callen and T. A. Welton, Phys. Rev. **83**, 34 (1951).

T10. Self-Consistent Statistical Model for the Many-Fermion Problem.* R. L. MILLS AND A. M. SESSLER, *The Ohio State University.*—The Thomas-Fermi self-consistent atomic model[1] is extended in a natural way by the use of the reaction matrix techniques of Brueckner and Bethe.[2] The total potential energy of the N-fermion system may be approximated[2] by the trace of the reaction matrix: in configuration space,

$$P.E. = \tfrac{1}{2}\int \Lambda(\mathbf{x}_3,\mathbf{x}_1)\Lambda(\mathbf{x}_4,\mathbf{x}_2)[\mathrm{K}(\mathbf{x}_1\mathbf{x}_2\mathbf{x}_3\mathbf{x}_4) - \mathrm{K}(\mathbf{x}_1\mathbf{x}_2\mathbf{x}_4\mathbf{x}_3)]d\mathbf{x}_1 d\mathbf{x}_2 d\mathbf{x}_3 d\mathbf{x}_4,$$

where $\mathrm{K}(\mathbf{x}_1\mathbf{x}_2\mathbf{x}_3\mathbf{x}_4)$ is the spatial representation of the reaction matrix, and $\Lambda(\mathbf{x},\mathbf{x}')$ is a projection operator onto the occupied single-particle states. The statistical approximation consists of assigning to each spatial point $\mathbf{x}$ a local Fermi momentum $\kappa(\mathbf{x})$, replacing $\mathrm{K}(\mathbf{x}_1\mathbf{x}_2\mathbf{x}_3\mathbf{x}_4)$ by the reaction matrix for an infinite medium (involving an average value of $\kappa(\mathbf{x})$), and evaluating $\Lambda(\mathbf{x},\mathbf{x}')$ in a plane wave approximation, which involves $\kappa(\mathbf{x})$ and $\kappa(\mathbf{x}')$. A variational equation for $\kappa(\mathbf{x})$ is obtained by minimizing the total energy while holding the total number of particles fixed, the kinetic energy and the number of particles being expressed in terms of $\kappa(\mathbf{x})$ in the usual way.[1] The resulting integral equation for $\kappa(\mathbf{x})$ is meaningful even for singular potentials, and, for the Coulomb interaction, reduces in the lowest approximation to the usual T-F equation.

* Research supported by the National Science Foundation.
[1] Gombas, "Statistische Behandlung des Atoms," *Handbuch der Physik* (Springer-Verlag, Berlin, 1956), Band 36, p. 109.
[2] Brueckner and Wada, Phys. Rev. **103**, 1008 (1956).

T11. Low-Lying States of Many Boson Systems. M. GIRARDEAU AND R. ARNOWITT, *Syracuse University.*—The low-lying eigenvalues and eigenstates of the pair Hamiltonian of a many boson system are determined. The spectrum is exact to within an additive constant in the limit as the number of particles approaches infinity. The elementary excitations of lowest momentum and energy are found to be phonons (i.e., density fluctuations). However, the phonon spectrum differs qualitatively from the results of previous calculations[1-3] in that the energy of a phonon does not vanish as its momentum approaches zero. The resulting energy gap separating all excited states from the ground state leads to conditions appropriate for superfluidity of the system at low temperatures.

[1] N. N. Bogolubov, J. Phys. (U.S.S.R.) **11**, 23 (1947).
[2] Lee, Huang, and Yang, Phys. Rev. **106**, 1135 (1957).
[3] K. A. Brueckner and K. Sawada, Phys. Rev. **106**, 1117, 1128 (1957).

T12. The Ground State of an Einstein-Bose System.* J. K. PERCUS AND G. J. YEVICK, *Stevens Institute of Technology.*—A trifurcate approximation method is employed to determine the states of an Einstein-Bose system, with two-body interactions, which resides in a periodic box. First, assuming that a finite Fourier series representation (in an unspecified sense) of the interaction potential has been obtained, the two-body correlation coefficients are extracted by the method of collective coordinates, valid for both perturbation and strong coupling limits. Then the condition that these coefficients be identical, for the actual and representative potentials, is transformed to the requirement that addition of a certain interaction between two particles alone leaves the correlation between these two particles unaltered. Finally, the modified wave function for the added potential is determined variationally, and the preceding requirement explicitly delineated. There results a set of self-consistent relations for the correlation coefficients; furthermore, the system energy may be obtained by a quantum mechanical virial therorem for containers with periodic boundaries. An expansion in density permits explicit computation of the second-order ground state correlation coefficients and an expression in quadratures for the corresponding energy; for example, the Lee-Huang-Yang results for the hard sphere pseudopotential are precisely reproduced.

* Supported by the Office of Naval Research.

SATURDAY MORNING AT 9:45

GRAND Ballroom

(H. A. BETHE presiding)

Invited Papers

TA1. Theory of Beta Decay. R. P. FEYNMAN, *California Institute of Technology.* (40 min.)

TA2. The Experimental Status of Beta Decay. MARTIN DEUTSCH, *MIT.* (30 min.)

TA3. Circular Polarization of Bremsstrahlung and Gamma Rays. MAURICE GOLDHABER, *Brookhaven National Laboratory.* (30 min.)

TA4. Polarization of Muons from *K*-Meson Decay: Measurements and Implications. W. A. WENZEL, *University of California, Berkeley.* (30 min.)

SATURDAY MORNING AT 9:45

Boston-Washington Room

(H. E. GOVE presiding)

Nuclear Reactions III

U1. Gyromagnetic Ratio of 2^+ Rotational States.* R. P. SCHARENBERG AND G. GOLDRING,† *Massachusetts Institute of Technology.*—The angular distribution of gamma rays following Coulomb excitation of millimicrosecond 2^+ states in Nd^{150}, Sm^{152}, Sm^{154}, Gd^{154}, Gd^{156}, and Gd^{160} were investigated. The gamma-ray angular distributions from solid oxide targets showed substantial perturbations. The attenuation coefficients for liquid nitrate targets were measured to be: Nd^{150}, $G_2{}^L=1\pm0.035$; Sm^{152}, $G_2{}^L=1\pm0.035$; Sm^{154}, $G_2{}^L=1.1\pm0.10$; Gd^{154}, $G_2{}^L=0.5\pm0.06$; Gd^{156}, $G_2{}^L=0.6\pm0.04$; Gd^{160}, $G_2{}^L=0.6\pm0.06$. The influence of the paramagnetic ion and the liquid environment on the angular distributions will be discussed. The effect of an external magnetic field (*Hex*) on the unperturbed gamma-ray angular distribution from liquid targets was measured. The effect was attributed to the precession of the excited nucleus (gyromagnetic ratio g) in the external magnetic field which has been modified by the atomic structure (*Heff*). For Nd^{150}, $Heff=(2.3\pm0.3)Hex$ $g=0.22\pm0.04$; Sm^{152}, $Heff=(1.7\pm0.2)Hex$ $g=0.21\pm0.04$; Sm^{154}, $g=0.17\pm0.04$.

* This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at the Weizmann Institute of Science, Rehovoth, Israel.

U2. Precision Determination of Energy Levels in Isotopes of Hf, Ta, and Re.* E. L. CHUPP, J. W. M. DUMOND,† F. J. GORDON, R. C. JOPSON, AND H. MARK,‡ *University of California, Livermore.*—The low-lying energy levels of the more abundant isotopes of Hf, Ta, and Re have been studied using the 3.7-Mev proton beam of the *A*-48 accelerator to excite the nuclei. The large available beam currents (~5 ma) give rise to gamma-ray source strengths large enough so that a bent quartz crystal spectrograph may be used to study the de-excitation gamma rays.[1] In Hf and Re the energies (in kev) of the first excited levels are: Hf^{176}, 88.33 ± 0.07; Hf^{177}, 112.90 ± 0.14; Hf^{178}, 93.13 ± 0.08; Hf^{179}, 122.71 ± 0.18; Hf^{180}, 93.28 ± 0.08; Re^{185}, 125.34 ± 0.22; and Re^{187}, 134.31 ± 0.28. In Ta^{181} the first excited level is observed at 136.13 ± 0.14 kev and the cascade gamma ray between the first and second excited levels is observed at 165.17 ± 0.22 kev. The rotational level formula[2] predicts an energy of 302.41 ± 0.31 kev for the second excited level, whereas the sum of the two gamma rays measured here is 301.30 ± 0.26 kev, showing a deviation of 1.21 ± 0.41 kev.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
† California Institute of Technology.
‡ Now at MIT.
[1] Chupp, Clark, DuMond, Gordon, and Mark, Phys. Rev. **107**, 745 (1957).
[2] A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selskab Mat.-fys. Medd. **27**, No. 16 (1953).

U3. Internal Conversion Electrons Following Coulomb Excitation of Dy^{161} and Dy^{163}.* E. M. BERNSTEIN† AND S. BUCCINO, *Duke University.*—The internal conversion electron spectra following Coulomb excitation of natural Dy and enriched Dy^{161} and Dy^{163} have been studied using a magnetic spectrometer. The following transitions were observed (energies in kev): Dy^{161}, 46, 59, 105 and Dy^{163}, 75, 95, 170. These transitions are assigned to the first two rotational states in each isotope. This is in agreement with recent gamma-ray measurements.[1] In addition the ground-state transition from a level at 164-kev is also observed in Dy^{163}. The conversion electron intensity from the latter transition is about one-third as large as the 170-kev transition. Assuming Bohr and Mottleson's rotational model to be valid the percentage of E_2 in the cascade transitions between the second and first rotational states are: Dy^{161}, 12 ± 4; Dy^{163}, $30_{-10}{}^{+15}$. The relative $B(E2)$ values for exciting the two rotational levels in each isotope, which are calculated using the above $E2$ to $M1$ mixing ratios, are consistent with the theoretical predictions within the experimental uncertainty.

* Supported by the U. S. Atomic Energy Commission.
† Now at the University of Wisconsin, Madison, Wisconsin.
[1] N. P. Heydenburg and G. F. Pieper (to be published).

U4. Yields of Photo-Alpha Particles. M. ELAINE TOMS AND JOHN MCELHINNEY, *U. S. Naval Research Laboratory.*—Alpha particles from thin foils of Al, V, Fe, Co, Ni, Cu, Cu^{65}, Zn, Nb, Rh, Ag, and In have been observed in nuclear emulsions. These target foils were placed between 100-micron thick, $E\cdot1$ Ilford emulsions and exposed to 21.5-Mev bremsstrahlung, hardened by 86.2 cm of graphite. The calculated ratio of the number of photons of energy >10 Mev (the effective photons) in the unhardened x-ray beam to the hardened beam was 13.35. When this factor was applied to the results for copper, a yield of $(3.1\pm0.4)\times10^4$ alphas $mole^{-1}R^{-1}$ at 21.5 Mev was

obtained. This value is in good agreement with a yield of $(3.9\pm0.6)\times10^4$ alphas mole$^{-1}R^{-1}$ previously obtained from copper bombarded by 22.0-Mev unhardened bremsstrahlung.[1] The following yields were obtained, in units of 10^4 alphas mole$^{-1}R^{-1}$: Al-1.5, V-0.5, Fe-2.3, Co-2.7, Ni-4.7, Cu-3.1, Cu^{63}-4.3, Zn-9.9, Nb-0.6, Rh-0.3, Ag-0.2, and In-0.1. The unexpectedly high yields from aluminum and zinc will be discussed.

[1] M. E. Toms and J. McElhinney, Bull. Am. Phys. Soc. Ser. II, 1, 192 (1956).

U5. Photoproton Cross Sections in C, O, and Al.* S. Penner and J. E. Leiss, *National Bureau of Standards.*—The (γ,p) cross sections from C, O, and Al have been measured at photon energies between 12 and 65 Mev at a lab angle of 90°. Essentially only the fraction of the reaction which leaves the residual nucleus in its ground state was detected. Transitions to the first excited state of the residual nucleus were detected with an efficiency of 10% or less of the efficiency for detecting ground-state transitions. The method used was to detect the protons from the reaction in a very thin CsI(Tl) scintillator. The minimum proton energy is determined by absorbers placed in front of the detector. The maximum proton energy is determined by the peak energy of the bremsstrahlung spectrum. The energy bin so chosen was 4 to 5 Mev. The measured cross sections in carbon are in agreement with the Pennsylvania results[1] at 23 Mev. Between 23 Mev and 65 Mev the carbon cross section decreases by a factor of about 400.

* This work was partially supported by the U. S. Atomic Energy Commission.
[1] Cohen, Mann, Patton, Reibel, Stephens, and Winhold, Phys. Rev. 104, 108 (1956).

U6. Photoneutron Cross Sections of Eu^{151} and Eu^{153}.* B. C. Cook and K. Geller, *University of Pennsylvania.*—A general broadening of the width of the giant resonance in photonuclear cross sections for nonmagic nuclides is now well established. The correlations of width with nuclear deformation for spheroidal nucleii has been suggested but is as yet unconfirmed. Since it is known from Coulomb excitation that the ground state of Eu^{151} is spherical while that of Eu^{153} is spheroidal, a measurement of the total γ-absorption cross section for these isotopes will yield evidence regarding the possible correlation. The yields of photoneutrons from enriched Eu^{151} and Eu^{153} have been measured from threshold (~8 Mev) to 24 Mev in 200-kev intervals using bremsstrahlung from a 25-Mev betatron. The shape of the two excitation curves is quite dissimilar. For Eu^{151} the curve is typical of curves obtained for most elements while Eu^{153} the curve is quite similiar to that of Ta, an element known to have a very broad cross section. The cross sections obtained by analysis of the yield curves will be presented.

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U7. Attachment Cross Section for Electrons by Fast Protons. R. J. Connor, P. H. Rose, and R. P. Bastide.—Proton beams were passed through targets of several gases and the cross section for electron attachment was measured for energies between 0.4 and 2.0 Mev. The neutral beam produced was measured calorimetrically and by monitoring the luminescence produced by the beam on a glass plate with a photomultiplier. The results are compared with the values predicted by theory.[1,2]

[1] T. Pradhan, Phys. Rev. 105, 1250 (1957).
[2] J. D. Jackson and H. Schiff, Phys. Rev. 89, 359 (1953).

U8. Inelastic Scattering of Deuterons.* J. L. Yntema and B. Zeidman, *Argonne National Laboratory.*—The inelastic scattering of 2.6-Mev deuterons by a number of elements (Au, Pt, Ag, Rh, Cu, Ni, Zn, Mg) has been measured at several angles with the Argonne 60-in. scattering chamber. The deuterons were detected by means of two NaI crystals. The product of the two signals was used to gate the 20-channel analyzers. The inelastic spectrum shows a structure which is dependent on angle. The cross section for inelastic scattering appears to be peaked in the forward direction. There is no indication of a strong increase in cross section with increasing excitation.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

U9. Miscellaneous Investigations of Anomalous Inelastic Scattering. Allen G. Rubin and Bernard L. Cohen, *Oak Ridge National Laboratory.*—Anomalous inelastic scattering of protons by heavy nuclei[1] has been investigated by (1) determining the dependence of the effect on incident proton energy, (2) measuring the energy spectra of the de-excitation gamma rays, and (3) studying the effect in regions of the periodic table previously inaccessible because of difficulties in target preparation. In (1), it was found that, in general, the peak occurs at the same Q value for bombarding energies between 22.5 and 12.5 Mev; this indicates that the effect is not a "giant resonance" phenomenon. The cross section decreases slowly (~40% over the energy range studied) as the incident energy is decreased. In (2), it was found that transitions direct to the ground state occur with ~10% probability; such transitions are thus not strongly forbidden as predicted by some theoretical explanations. Some gamma rays do occur in a large precentage of cases; their significance will be discussed. In (3), the region between atomic numbers 54 and 71, 30 and 40, and isolated heavy nuclei are being studied; results will be presented. Preliminary data indicate that the cross section decreases from atomic numbers 54 to 62.

[1] B. L. Cohen, Phys. Rev. 105, 1549 (1957); B. L. Cohen and S. W. Mosko, Phys. Rev. 106, 995 (1957).

U10. 23-Mev Proton-Induced (p,α) Reactions. Clyde B. Fulmer and Bernard L. Cohen, *Oak Ridge National Laboratory.*—(p,α) reactions induced by 23-Mev protons in various elements throughout the periodic table were studies by observing the outgoing alpha particles. Alpha-energy distributions and absolute differential cross sections were measured at 30°, 60°, 90°, 120°, and 150°. For atomic numbers $\gtrsim50$ the energy spectra are characterized by broad maxima which fall sharply to zero on the low-energy side, Maxima occur at energies far below the Coulomb barrier for $r_0\simeq1.5$ fermis; this cannot be explained as a product of level density functions and Coulomb barrier penetration factors since this leads to total (p,α) cross sections many orders of magnitude too small. It indicates that the alpha particles are formed at a distance corresponding to $r_0\simeq1.9$ fermis. Angular distributions are peaked forward, but the anisotropies are not large except in the high-energy tails. In the heaviest elements angular distributions are strongly forward and the maxima in the energy spectra occur near the highest energy. All of this evidence strongly indicates that the principal interaction is of a noncompound nucleus type. Total cross sections vary from ~100 mb for $Z\lesssim35$ to ~3 mb for Pt.

U11. Magnetic Analysis Studies of 23-Mev Proton Inelastic Scattering. Bernard L. Cohen and Allen G. Rubin, *Oak Ridge National Laboratory.*—The high-energy portion of the proton energy spectrum from inelastic scattering of 23-Mev protons by 25 medium weight and heavy elements was studied with 150–200 kev resolution utilizing magnetic analysis. At excitation energies between 0.2 and 1.8 Mev, the strongest groups are those leading to the lowest collective vibrational levels; their cross sections are strongly correlated with the reduced widths of these levels found from Coulomb excitation. The second vibrational levels are also excited,

but with cross sections an order of magnitude smaller. The region between 1.8 and 4 Mev excitation is characterized by strong maxima with energies and cross sections extraordinarily regular from element to element, as was found previously in measurements with scintillators[1]; in several elements, more detailed structure was resolved than in the scintillation work, but there is little marked similarity in this detailed structure between neighboring elements or between isotopes of the same element. The cross sections for these maxima is of the same order as those for excitation of the lowest vibrational states. Sharp structure is found in the spectra of almost all elements out to 4.5 Mev; in some elements, it extends much farther.

[1] B. L. Cohen, Phys. Rev. 105, 1549 (1957); B. L. Cohen and S. W. Mosko, Phys. Rev. 106, 995 (1957).

U12. Measurement of He^3 and He^4 Produced by High-Energy Protons in Iron.* O. A. SCHAEFFER AND J. ZÄHRINGER,† *Brookhaven National Laboratory.*—A high-sensitivity mass spectrometer has been used to measure the He^3 and He^4 produced in iron by 0.16-, 0.41-, and 3.0-Bev protons. The spectrometer had a sensitivity of 1.4×10^{-10} cc NTP/mv for He^4. The background at He^4, determined by melting a piece of unbombarded iron, was about 10^{-9} cc He^4 at NTP. The background at He^3 was lower by about a factor of 10. The ratio of gas measured to background was always at least 20. The results are summarized in Table I. The results will be discussed in relation to evaporation theory and the helium content of iron meteorites.

TABLE I. Helium produced by protons in iron.

Proton energy, Bev	0.16	0.41	3.0
σ, mb for He^4	120	450	1300
He^3/He^4	0.10	0.10	0.18

* Research performed under the auspices of the U. S. Atomic Energy Commission.
† Assisted by the Deutsche Forschungsgemeinschaft.

U13. Radiochemical Studies of the (p,pn) Reaction in Complex Nuclei in the 82–426 Mev Range. H. P. YULE AND ANTHONY TURKEVICH, *University of Chicago.*—Cross sections for the reactions $F^{19}(p,pn)F^{18}$, $Cu^{65}(p,pn)Cu^{64}$, and $Au^{197}(p,pn)Au^{196}$ have been measured in the energy range 82–426 Mev. These cross sections are based on the absolute values of Crandall *et al.*[1] for the reaction $C^{12}(p,pn)C^{11}$. The three excitation functions decrease quite rapidly with increasing energy in the lower end of the energy range and then level off to a very slight downward energy trend above 250 Mev. Cross sections range from 122 mb for Au^{197} at 82 Mev to 23 mb at 426 Mev for F^{19}. Our cross sections for F^{19} and Cu^{65} at 426 Mev are about twenty percent higher than the value published by Markowitz *et al.*[2] in their study of (p,pn) reactions above 400 Mev. Cross sections for these and other (p,pn) reactions have been calculated from the Monte Carlo calculations of Metropolis *et al.*[3] combined with evaporation theory. The theoretical results for the reactions $Cu^{65}(p,pn)Cu^{64}$ and $Au^{197}(p,pn)Au^{196}$ are low by factors of two and three low, respectively. The extrapolation of the Monte Carlo calculation from Al^{27} to F^{19}, gives good agreement in this case.

[1] Crandall, Millburn, Pyle, and Birnbaum, Phys. Rev. 101, 329 (1956).
[2] Markowitz, Rowland, and Friedlander, Bull. Am. Phys. Soc. Ser. II, 1, 244 (1956).
[3] Bivens, Metropolis, Turkevich, Miller, and Friedlander, Bull. Am. Phys. Soc. Ser. II, 2, 63 (1957); (to be published).

SATURDAY MORNING AT 9:45

Terrace Room

(W. A. HIGINBOTHAM presiding)

Apparatus of Nuclear Physics

UA1. Scanning Field Alternate Gradient Accelerators.* TOSHIO KITAGAKI, *Princeton University.*—A kind of AG focusing is obtained by the alternate combination of radial sector dc guiding fields and quadrupole focusing fields of opposite high gradient. The focusing field is radially shifted, increasing its gradient as the beam energy goes up. This scanning field is analogous to the rotating field in rotating machines and is produced by successive pole face windings. The ion dynamics are similar to that of the radial sector FFAG, however the average radius is small in this case ($\sim30m$ for 10-Bev proton s.t.). The beam is injected into a large aperture ($\sim40\times70$ cm²) and shifted continuously to a smaller aperture ($\sim4\times8$ cm²). Since the scanning field supplies only the gradient in a limited region, its maximum field and stored energy are small (~3 *kG*, 2×10^6 joules), and hence the scanning rate can be much higher than the repetition rate of conventional ac machines. These considerations indicate the possibility of high-intensity accelerators in the 1 to 100-Bev range which utilize this principle.

* Supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

UA2. The 8/4 Resonance and Beam Extraction from the AVF Cyclotron. M. M. GORDON* AND T. A. WELTON, *Oak Ridge National Laboratory.*—The AVF (spiral-sector) cyclotron being developed at Oak Ridge National Laboratory is designed to accelerate protons with fixed orbital frequency up to the integral radial resonance $\nu_r=2$ (~850 Mev). For an 8-sector machine, this point coincides with the 8/4 nonlinear essential resonance which leads to radial instability. An investigation has been carried out to determine the feasibility of utilizing this instability to achieve efficient beam extraction. Extensive phase space maps of orbit invariants appropriate to this resonance have been obtained from numerical computations. These results show that this resonance will provide large radial amplitude growth rates without mutilating the radial phase area occupied by the beam. The maximum growth rate attainable in practice is limited by the effects of the $\nu_r=2\nu_z$ coupling resonance. A growth rate of 4 cm/turn has been obtained without significant deterioration in the vertical motion. Beam extraction can be effected by small $\cos2\theta$-field bumps which "steer" the beam into the 8/4 resonance which then rapidly builds up the amplitude until the beam enters the exit channel.

* On leave from the University of Florida.

UA3. Resonant Inflection in Alternating Gradient Synchrotrons. T. A. WELTON, *Oak Ridge National Laboratory.*—An AVF cyclotron is capable of supplying an intense proton beam at energies near 1 Bev and with optical characteristics

well-suited to synchrotron injection. A large performance advantage can be achieved by use of an alternating gradient synchrotron, but conventional single turn injection is both wasteful and difficult with such a beam. Suppose, however, that the radial frequency is made a quarter odd integer and certain frequency relations are maintained between the synchrotron and cyclotron oscillators during injection. Successive pulses from the cyclotron can then be introduced parallel to the equilibrium orbit with large amplitude, by use of a conventional magnetic channel. A cavity with radial electric field and sextupole shape, with frequency one-quarter of the accelerating cavity, can then cause steady reduction of radial amplitude, by a simple resonance effect, and thus cause the beam to clear the channel wall. High efficiency in filling the synchrotron phase space is expected, with rather simple apparatus. Detailed calculations will be presented which allow simple estimation of the number of turns of injected beam which can be accepted.

UA4. On the Use of Very Strong Focusing Magnetic Lenses. MALCOLM A. MACLEOD,* *Boston College*, AND R. W. WANIEK, *Harvard University and MIT.*—With the development of pulsed magnets operating up to a megagauss[1-3] it becomes of practical importance to analyze the performance of magnetic lenses at these high fields. Assuming a Glaser-type, bell-shaped distribution for the fields, $H_z=H_0/\{1+(z/a)^2\}^\mu$, the paraxial equation can be applied to yield universal curves for different values of the parameter $k^2=(2.25\cdot10^4B^2a^2)/(T^2+2TE_0)$, giving a complete description of the particle trajectories. Curves for k^2 ranging from 0.1 (conventional magnetic lenses) to 10^4 have been obtained for different injection points and angles by evaluation with an IBM 704 computer. The usefulness of these lenses for strong focusing of nuclear particles of high energies and for the compression of beams will be discussed.

* Now at Brandeis University.
[1] H. P. Furth and R. W. Waniek, Nuovo cimento **3**, 1350 (1955).
[2] H. P. Furth and R. W. Waniek, Rev. Sci. Instr. **27**, 195 (1956).
[3] Furth, Levine, and Waniek, Rev. Sci. Instr. **28**, 949 (1957).

UA5. An Ionization Gauge Detector for Molecular Beams.* F. C. HURLBUT, *University of California.*—The application of ionization gauges to the detection of molecular beams is discussed and the performance of an existing detection system for surface scattering studies is described. Beams of argon and of nitrogen have been employed to the present writing. Minimum resolvable pressure increments within the gauge volume due to the beam are of the order of 10^{-11} mm Hg. Limitations of the system are considered in relation to those of other currently available detection systems.

* Work jointly sponsored by the Office of Naval Research and the Office of Scientific Research.

UA6. A New Design for an Angular Distribution Chamber. R. L. CLARKE, *Chalk River Laboratories.*—A nuclear reaction chamber convenient for studying the angular distribution of charged particles using magnetic analysis has been developed. It permits the examination of particle groups emitted in the horizontal plane between $-25°$ to $+144°$ with respect to the incident horizontal beam and is employed in conjunction with a Kellogg magnet[1] and the Chalk River electrostatic accelerator. The scanning motion of the outlet port of the chamber is produced by the action of three rotating O-ring seals which are geared together and driven by a single motor. Thus it is possible to move the outlet port over the whole range without breading the vacuum. The motor is controlled, in turn, by the movement of the Kellogg magnet on its circular, horizontal track. The kinematic principles of the chamber will be given, and a sample of the results that can be obtained, taken from the $Be^9(He^3,p)B^{11}$ reaction, will be shown.

[1] Snyder, Rubin, Fowler, and Lauritsen, Rev. Sci. Instr. **21**, 852 (1950).

UA7. Study of the Mechanism of Bubble Formation in a Propane Bubble Chamber.* WALTER I. GOLDBURG, *Carnegie Institute of Technology.*—To help put a lower limit on the sensitive time of organic liquids commonly used in bubble chambers a static electric field of 15 kev/cm was applied across a small propane bubble chamber which was then expanded in the conventional manner when a beam of 350-Mev protons was passed through it. The bubble density along the tracks was measured with both field on and field off. Within statistics (±4%) no difference in bubble density was observed for the two cases. Using a thermodynamic model of bubble formation in superheated liquids[1] in conjunction with known energy loss data, it is concluded from the foregoing experiment that the sensitive time of propane is less than a microsecond, making the development of a triggerable bubble chamber difficult, if not possible. From the thermodynamic model it is possible to calculate the pressure for spontaneous boiling as a function of temperature. This has been done for propane, hydrogen, and helium. These results are compared with measurements made in this and other laboratories.

* This work is supported by the U. S. Atomic Energy Commission.
[1] W. Doring, Z. physik. Chem. (B)36, 373 (1937).

UA8. Thirty-Inch Propane Bubble Chamber.* WILSON M. POWELL, WILLIAM B. FOWLER, AND LARRY OSWALD, *University of California.*—Hydrostatic support has been used to make operational a large propane bubble chamber measuring 30 by 18 by 6.5 in. mounted in a magnetic field of 14 000 gauss. Successful pictures have been made at the Bevatron in a K^+ beam at ten picture per minute. The oil container forms the top pole and part of the bottom pole of the magnet. Photographs are taken through two small glass windows at the top of the magnet. The oil pressure is varied by compressed air separated from the oil by a cylindrical rubber diaphram. The beam enters a 2×9-in. window, and must pass through two ¼-in. thick pieces of stainless steel and 1 in. of oil before reaching the propane.

* This work was supported by the U. S. Atomic Energy Commission.

UA9. Plastic Filament Scintillation Counters and Chambers.* GEORGE T. REYNOLDS AND P. E. CONDON, *Princeton University.*—Filaments of plastic scintillation material have been formed and prepared as scintillation counters of various sizes up to several inches in dimension. The filaments act as light pipes for the scintillation light output when charged particles pass through the array. The diameters of the filaments have been the order of 0.5 mm. The performance of these counters has been compared to solid plastic scintillators of the same dimensions, and the light output of the filament array is found to be about 60% of that of the solid. The application of the filaments to scintillation chambers utilizing image intensifier tubes will be discussed.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

UA10. Some Performance Characteristics of the Evapor-Ion Vacuum Pump.* H. LUCKS, R. GRAETZER, I. SHERMAN,† AND E. WESTERBERG, *University of Wisconsin.*—A 12-in. Evapor-Ion vacuum pump was constructed using an evaporator and feeder mechanism differing from pumps previously described. Measurements of the pumping speeds of CO_2, NH_3, and water vapor indicated that they are gettered by titanium since pumping speeds were independent of ionization current. Pumping speeds of several thousand liters per second were obtained for each of these gases. Sulfurhexafluoride and butane showed some gettering and pumping speeds of these materials were about 100 l/sec. Methane, ethane, propane, and isobutane were not pumped without ionization.

Attempts are being made to decompose these hydrocarbons at low pressures. Some experiments with CuO and alumina gave negative results. Attempts were made to compare the gettering action of zirconium with titanium. Evaporators made of graphite, tantalum, tantaloy, and tungsten disintegrated before accurate measurements could be made. Data obtained showed no appreciable difference in the gettering action between these two metals. Studies have been made of pump starting procedures with several electrode arrangements. Evaporation was initiated at pressures easily reached with a forepump.

* Work supported by the National Science Foundation and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
† Now at Argonne National Laboratory.

UA11. Design and Construction of Two-Inch Evapor-Ion Pump.* R. A. Frosch, W. R. Dahl, James D. Elbert, and R. G. Herb, *University of Wisconsin.*—Following from the large size Evapor-Ion pump this pump has been developed to reduce the size and power requirements needed to obtain a clean vacuum, typical of a pump of this type. The pump has a throat diameter of 2 in. and an over-all height, including electrical terminals, of 10½ in. Materials used in the construction of this unit and construction methods are such that a bakeout up to 500°C is possible. Wire is stored in a coil inside the pump and is fed to the evaporation region by means of a compact electromagnetic device. The wire passes through a coiled tungsten filament where it is heated by electron bombardment and is evaporated. Evaporation has been studied from several types of stranded wire. When power is properly controlled complete and smooth evaporation has been obtained.

* Work supported by the National Science Foundation and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.

UA12. Performance of Two-Inch Evapor-Ion Pump.* W. R. Dahl, R. A. Frosch, and R. G. Herb, *University of Wisconsin.*—In general performance characteristics the 2-in. pump is similar to large sized Evapor-Ion pumps but with lower pumping speeds. For starting, the pump is baked out—this during the roughing period. After the pump is cooled, evaporation may be commenced and the valve to the forepump should be closed. The wire to be evaporated is maintained at about 1000-v positive, and current required for evaporation is about 0.015 A. Inert gases are ionized by electrons flowing from the filament to a fine wire grid below the evaporation region. As ions drift outside the grid they are accelerated to the pump wall where some are trapped in the titanium layer. The grid is normally at 600 v positive and draws a current of about 0.015 ampere. Filament heating power is 55 w and thus over-all power consumption is about 80 w. Air from a small blower cools the pump wall. Some values obtained for pumping speeds are oxygen at a pressure of 2×10^{-6} mm of Hg, 35 l/sec, hydrogen at 5×10^{-6} mm of Hg, 45 l/sec, argon at pressures between 1×10^{-6} and 1×10^{-6} mm of Hg, 0.04 l/sec. The grid is now being rearranged to permit use of higher electron currents so as to obtain higher pumping speeds for argon.

* Work supported by the National Science Foundation and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.

Saturday Morning at 9:45

Governor Clinton

(G. J. Dienes presiding)

General Solid-State Physics

V1. Monte Carlo Investigation of the Order-Disorder Transformation in a Body-Centered-Cubic Structure. P. A. Flinn, G. M. McManus, and James Bardeen, *Westinghouse Research Laboratories.*—The order-disorder transformation has been investigated for a binary b.c.c. structure by a Monte Carlo calculation based upon the mechanism of vacancy diffusion in a disordered lattice, assuming only nearest neighbor interactions. In this treatment the vacancy jumps with a probability weighted according to an A-B interaction energy/kT. Both the long-range order and the short-range order parameters are calculated during the diffusion until a steady state is attained. Thus both the equilibrium value of the order parameters and the kinetics of the ordering process are obtained.

V2. On New Types of Order-Disorder Phase Transitions in Some Complex-Ion Salts.* Y. Okaya, N. Stemple, S. Hoshino, and R. Pepinsky, *Pennsylvania State University.*—New order-disorder transitions have been found in cubic crystals of

$[Co(NH_3)_6](ClO_4)_3$, $[Co(NH_3)_6](BF_4)_3$, $[Co(NH_3)_6]SO_4Br$,

and

$[Co(NH_3)_5H_2O](ClO_4)_3$.

In these the large complex ions dominate the packing of the structures, and the smaller ions have some freedom in position and orientation. The transitions have been examined optically, by x-rays, and thermally. The ordered phase has a superstructure lattice with cell constant twice that of the disordered phase. Remaining short-range order in the disordered phase is revealed by maxima in diffuse scattering in stationary-crystal photographs taken with filtered Co$K\alpha$ radiation. Results are discussed thermodynamically, and are compared with nuclear magnetic resonance measurements obtained by Murray[1] on $[Co(NH_3)_6](BF_4)_3$.

Crystal	Transition point (s)	Energy, kcal/mole	Entropy, cal/mole-deg
$[Co(NH_3)_6](ClO_4)_3$	61°C	0.31	0.93
$[Co(NH_3)_6](BF_4)_3$	−2°C	0.21	0.78
$[Co(NH_3)_5\cdot(H_2O)](ClO_4)_3$	41°C	0.28	0.89
$[Co(NH_3)_6]SO_4\cdot Br$	125°C and 140°C	0.33 and 1.62	0.83 and 3.95

* Supported by U. S. Air Force Office of Scientific Research and U. S. Army Signal Corps Engineering Laboratories.
[1] G. Murray, thesis, MIT (1956).

V3. Dislocation Arrangements in Plastically Bent Silicon Crystals.* J. R. Patel, *Raytheon Manufacturing Company* (introduced by J. Lavine).—Dislocations introduced into single crystals of silicon by plastic bending at an elevated temperature have been studied quantitatively by the etch pit technique. The average etch-pit density after deformation is approximately two to three times higher than the calculated dislocation density. Prolonged annealing of the deformed

samples at a temperature close to the melting point results in polygonization or the alinement of etch pits perpendicular to the active slip planes. Satisfactory agreement was obtained between the densities of etch pits in the annealed and polygonized specimens and the predicted dislocation densities. Pileup horizontal arrays of etch pits have been observed in lightly bent samples. The calculated value of yield stress obtained from the geometrical distribution of these arrays is an order of magnitude below the reported experimental values. Dislocation lines in single crystals deformed very lightly at 1000°C have been revealed by the technique of copper decoration. Examination of the decorated samples by infrared transmission microscopy revealed that the dislocation lines lie in the [211] direction.

* Supported in part by the Bureau of Ships.

V4. Detection of Optical Lattice Vibrations in Ge and ZrH by Scattering of Cold Neutrons.* I. PELAH,† C. M. EISENHAUER, D. J. HUGHES, AND H. PALEVSKY, *Brookhaven National Laboratory.*—Lattice vibrations in solids can be studied by measuring the momentum distribution of scattered cold neutrons that have exchanged energy with the lattice. In experiments now under way at the Brookhaven reactor, an incident cold neutron beam is produced by filtering the neutron flux with Be, and the velocity of the scattered neutrons in a given direction is measured by the slow chopper, time-of-flight method. In germanium, as in most elements, the nuclear scattering amplitude is mainly coherent, and the spectrum of neutrons inelastically scattered from a single crystal consists of discrete peaks. Among the peaks observed for germanium is one associated with a transverse optical mode of vibration in the crystal. As the momentum of this mode tends to zero, a limiting frequency corresponding to an energy of 0.037 ev is observed. In vanadium and hydrogenous materials the nuclear scattering amplitude is mainly incoherent, and the spectrum of neutrons scattered by acoustical modes has a continuous distribution. Only an optical mode can produce a sharp peak. Such a peak is observed for ZrH, indicating an optical mode of vibration with an energy of 0.130 ev.

* Work performed under contract with U. S. Atomic Energy Commission.
† On leave from Weizmann Institute, and the Atomic Energy Commission of Israel.

V5. Dispersion of Elastic Waves in Cubic Lattices with Central Forces. A. B. BHATIA, *University of Alberta.*—Assuming the interaction potential energy between two atoms distant r apart to be $W(r^2)$, general expressions for the dispersion (frequency-wave number) relations are derived for elastic waves propagating along the (100), (110), and (111) directions in body-centered and face-centered-cubic lattices. If $W(r^2)$ is assumed to be appreciable for the first and second neighbors only, it is found that, while the two independent elastic constants c_{11} and $c_{12}=c_{44}$ involve only the two force constants occurring in the customary quasi-elastic central force model, the dispersion relations contain an additional constant. A numerical example shows that the additional term may contribute several percent to the frequencies at small wave numbers.

V6. Anelasticity of Synthetic Quartz at Low Temperatures.* J. C. KING, *Bell Telephone Laboratories.*—The anelasticity of quartz grown by hydrothermal synthesis from various seed plate orientations has been measured at low temperatures. The technique employed involves the measurement of the Q of precision AT-cut quartz resonators fabricated from synthetic quartz. The amplitude of a stress induced relaxation absorption occurring at 50°K for a frequency of vibration of 5 megacycles is found to be several orders of magnitude larger in synthetic quartz than in natural quartz.[1] In general the height of the absorption peak at 50°K in synthetic quartz is dependent upon the direction in which the quartz was grown. This suggests that the crystal imperfection underlying the absorption is selectively incorporated in the crystal. X-ray irradiation of synthetic quartz reduces the 50°K absorption by at least two decades but induces another relaxation absorption at 100°K. The similarities between these mechanical loss measurements and dielectric loss measurements[2] on synthetic quartz will be discussed. Possible defect structures, common to the quartz, will be examined in the light of these investigations.

* This work was partially supported by the U. S. Army Signal Corps.
[1] Bömmel, Mason, and Warner, Phys. Rev. 102, 64 (1956).
[2] J. Volger, Fifth International Conference on Low Temperature Physics (1957).

V7. New One-Dimensional Crystal Model. F. L. SCARF, *University of Washington.*—The Schrödinger equation for $V(x)=-V_0\csc^2(\pi x/a)$ is solved with periodic boundary conditions. Although $V(x)$ is singular, even and odd elementary cell solutions are chosen to make the potential equivalent to one which has repulsive core cutoffs at the lattice points. The problem is then completely soluble, and the effective mass, allowed energies, band edge wave functions, and many other quantities can be expressed in closed form as simple functions of V_0, a and the crystal momentum, $\hbar k$. When $V_0a^2\to 0$, $m^*\to m_0$ (all k within the bands) and, as V_0a^2 tends to a (finite) critical value, $m^*\to\infty$ (all k). This suggests that the weak and tight binding approximations, respectively, should be valid in these regions, but it is actually found that they are inappropriate. The result illustrates Slater's conjecture that the wave functions may be quite complicated even when m^* and $B(k)$ have forms which indicate that the particle is almost free or that it is tightly bound.

V8. Infrared Absorption by Sodium Chloride-Type Lattices. HERBERT B. ROSENSTOCK, *U. S. Naval Research Laboratory.*—In an attempt to explain the discrepancy between the experimentally observed far infrared lattice absorption by ionic crystals[1] with the prediction of the classical theory,[2] it has been shown[3,4] that, if the lattice-dynamical problem is solved without neglect of the correct boundary condition, several subsidiary peaks are found in addition to the principal absorption line. A computation has been made of the frequencies at which the vibrational motion of the atoms in a crystal of the NaCl structure should produce absorption. The results are evaluated for those alkali halides for which both compressibility and lattice distance are known; it is found that experimental absorption measurements made on thin evaporated films[1] are fitted more closely by some of the four subsidiary frequencies than by the classical limiting frequency.

[1] M. R. B. Barnes, Z. Physik 75, 723 (1932); R. B. Barnes and M. Czerny, Z. Physik 72, 477 (1931).
[2] M. Boron and M. G. Mayer, *Handbuch der Physik* (Springer-Verlag, Berlin, 1933), 24/2, p. 632, Sec. II.
[3] H. B. Rosenstock, J. Chem. Phys. 23, 2415 (1955).
[4] H. B. Rosenstock, J. Chem. Phys. 27, 1194 (1957).

V9. Light Scattering by Nearly Perfect Ionic Crystals. I.* O. THEIMER, *University of Oklahoma.*—The theory of light scattering by crystals is developed in a form adapted to modern theories of lattice imperfections. In addition to thermal scattering, configurational scattering of two different types is considered: (1) scattering by macroscopically homogeneous distributions of point imperfections (vacancies, impurities) characterized by their concentration, polarizability, and radial distribution function; (2) scattering by bad regions in the neighborhood of dislocation lines characterized by their size, shape, and index of refraction. Interpreting recent scattering experiments in terms of this theory, one estimates that single crystals of Harshaw sodium chloride have a dislocation density between 10^7 and 10^9 cm^{-2}, an

average vacancy concentration between 10^{16} and 10^{17} cm^{-3} and bad regions with an average diameter of about 1000 A and an excess vacancy concentration of about 10^{18} cm^{-3}.

* Sponsored by the Office of Ordnance Research, U. S. Army.

V10. Light Scattering by Nearly Perfect Ionic Crystals. II.* C. A. PLINT, *University of Oklahoma*.—The wavelength and angular dependence and polarization of Rayleigh scattering in NaCl and KCl crystals have been investigated. The results show significant deviations from the behavior predicted by the theory of thermal scattering. In particular the wavelength dependence of the scattering power does not follow the Rayleigh λ^{-4} law, and the intensity of the scattering is an order of magnitude greater than the thermal value. The results will be discussed in terms of imperfections in a nearly perfect crystal.

* Sponsored by the Office of Ordnance Research, U. S. Army.

V11. New Method for the Ground-State Energy and Effective Mass of the Polaron. E. LIEB, *University of Illinois*, AND K. YAMAZAKI, *Max Planck Institut, Göttingen*.—The polaron Hamiltonian would be easily soluble were it not for the quartic term appearing therein. It is proposed to substitute for the quartic term a quadratic term having roughly the same properties, and in such a way that the ground-state energy of the new Hamiltonian is rigorously a *lower bound* for the true energy. With a very small amount of work one can obtain a lower bound as a continuous function of α for all values of α. The result agrees fairly well with the results obtained by other methods. Using the equivalent Hamiltonian, one also can obtain an analytic expression for the effective mass, but one cannot say it is a bound for the true effective mass. Moreover, once one has obtained a lower bound as a continuous function of the parameters of the Hamiltonian, one can rigorously derive upper and lower bounds for the expectation values of various operations. For example, it can be shown that for large α and large k, $\langle a_k^* a_k \rangle \sim K^{-4}$ and not $\exp(-K^2)$ as in Pekar's solution. Because of its simplicity, it is possible that this method may have application to other ground-state problems.

V12. Structure of the *H* Center. W. KÄNZIG AND T. O. WOODRUFF, *General Electric Research Laboratory*.—*H* centers were created in KCl crystals by x-irradiation at 20°K, as well as by irradiating 3650 A light at 20°K on crystals x-rayed previously at 78°K. The hyperfine spectrum of the *H* center studied by means of electron spin resonance reveals that the *H* center involves a hole that interacts mainly with four chlorine nuclei lying in a straight row along a [110] axis of the crystal. The two inside nuclei in the row are equivalent to each other, and so are the two outside nuclei. The hyperfine splitting due to the two inside nuclei is much larger than the hyperfine splitting due to the two outside nuclei. The hyperfine interaction with all four nuclei is roughly axially symmetric, with the axis along the row. In contrast to the Cl_2^- center the *H* center cannot be created in large concentration by a short x-irradiation of KCl:Tl at 20°K, indicating that the *H* center involves vacancies or interstitials. The corresponding defect in LiF was also studied.

SATURDAY MORNING AT 9:45

Panel Room

(N. H. LAZAR presiding)

Beta and Gamma Emitters I

VA1. Internal Conversion in Li^7.* RICHARD D. LEAMER, *Carnegie Institute of Technology* (introduced by George W. Hinman).—Upper and lower limits have been placed on the internal conversion coefficient of the 479-kev excited state of Li^7. The measurement was made in a large double-focusing beta spectrometer by comparing the conversion coefficient with that of the 662-kev gamma ray from Ba^{137}. The total conversion coefficient was found to be between 16.6×10^{-7} and 5.8×10^{-7}. The multipole mixture of the gamma ray is (100%–55%) *M*1 and (0%–45%) *E*2. The major experimental difficulties were chemical impurities in the source material and finding the background counting rate.

* Supported by the U. S. Atomic Energy Commission.

VA2. Negative Electron Distribution Accompanying the Na^{22} Positron Decay.* J. H. HAMILTON, L. M. LANGER, AND W. G. SMITH, *Indiana University*.—A negative electron distribution from Na^{22} was studied in a magnetic spectrometer. Two vacuum-evaporated, carrier-free sources were used, each of less than 10 μg/cm^2. One source was on a backing of 180 μg/cm^2 Al and the other on an aluminized zapon and LC 600 laminated on 20 μg/cm^2. Each source was covered with a 10 μg/cm^2 zapon film. An electron distribution was observed which decreased rapidly with energy, approaching the background in the region between 40 and 150 kev. For the source with thinner backing, the measured ratio N_{β^-}/N_{β^+} was $2.2(+0.9,-1.6)$% for energies >2 kev. If one includes a smooth extrapolation of the experimental curve to zero energy, N_{β^-}/N_{β^+} becomes $4.9(+1.2,-3.4)$%. The source on aluminum backing yielded a slightly higher ratio, not significantly outside the large limits of error arising from the low counting rates. An additional cover film of 10 μg/cm^2 made no change in the measured distribution or the total intensity at energies above 11 kev. Within the limits of error, the observed effect can be interpreted as "shake off" electrons in agreement with the calculations of Migdal and Levinger.[1]

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission and by a grant from the Research Corporation.

[1] J. S. Levinger, Phys. Rev. **90**, 11 (1953).

VA3. Reactions for the Production of P^{33}.* JAMES E. RUSSELL, *Yale University*.—P^{33} was produced along with P^{32} by neutron bombardment of natural sulfur in a section of the Brookhaven pile which contained no fuel elements and had an enhanced slow to fast neutron ratio. The half-life of P^{33} was determined from analysis of the decay curve of the P^{32}-P^{33} mixture taken with a Lauritsen electroscope and followed for 340 days. The measured value for the half-life of P^{33} was 25±1 days, in agreement with previous measurements.[1,2] The end point energy of the single beta released in the decay $P^{33}(\beta^-)S^{33}$ was measured with a magnetic lens spectrometer as 0.238±0.005 Mev. The reaction $Si^{30}(\alpha,p)P^{33}$ as a means of production of P^{33} was also studied and compared with the reaction $Si^{29}(\alpha,p)P^{32}$. At bombarding energies of 8

Mev the yield of the P^{33} reaction is much lower than that of the comparable P^{32} reaction. Explanation for this will be considered.

* Work supported by the John A. Hartford Foundation.
[1] Jensen, Nichols, Clement, and Pohm, Phys. Rev. 85, 112 (1952).
[2] Westermark, Phys. Rev. 88, 573 (1952).

VA4. Radiations of Co^{55}.* AMBUJ MUKERJI,† V. S. DUBEY,‡ AND S. S. MALIK,§ *Bartol Research Foundation.*—The radiations of Co^{55} have been studied in a thin lens magnetic beta-ray spectrometer and in coincident scintillation spectrometers. By observation of the internal conversion lines and the uncoverted gamma spectrum, gamma rays of energies 1410, 937, 476, and 247 kev have been resolved. No other gamma ray of higher energy decaying with an 18*h* half-life could be observed after careful search of that region using a 4¼-in. diam and 4-in. thick NaI(Tl) crystal. The Fermi-Kurie analysis of the positron spectrum yielded three groups of positrons of maximum energies 1510(51%), 1040(45%), and 790(4%) kev. These measurements revealed energy levels of the residual nucleus, Fe^{55}, at 937, 1410, and 1657 kev. A decay scheme will be presented.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† On leave of absence from the Tata Institute of Fundamental Research, Bombay, India. Present address: A and M College of Texas.
‡ Present address: Physics Department, Agra College, Agra, India.
§ Permanent address: Muzaffar Nagar (U.P.), India.

VA5. Decay of Cu^{62}. J. W. BUTLER AND C. R. GOSSETT, *U. S. Naval Research Laboratory.*—The gamma rays following the positron decay of Cu^{62} have been measured in terms of both energy and intensity with respect to the positron annihilation radiation. The Cu^{62} source was produced from the (p,γ) reaction by bombarding a thick isotopic Ni^{61} target with a beam of 1.8-Mev protons from an NRL Van de Graaff accelerator. The gamma rays were detected with a 3-in. ×3-in. NaI(Tl) crystal and a 256-channel pulse height analyzer. The gamma-ray energies are 0.69, 0.88, 1.13, and 1.17 Mev with uncertainties of ±0.02 Mev or less. The intensities are less than 1% of the positron intensity. Coincidence techniques and half-life measurements were used to identify the gamma rays with the decay of Cu^{62}. No gamma rays were observed higher than 1.17 Mev, and it is believed that any such gamma ray would have been observed if its intensity was greater than about 10% of that for the 1.17-Mev gamma ray. All gamma rays, except the 0.69-Mev gamma ray, fit very well into the Ni^{62} level scheme found by Spencer *et al.*[1] by observing the inelastically scattered protons from a Ni^{62} target.

[1] Spencer, Phillips, and Young, Phys. Rev. 108, 69 (1957).

VA6. Gamma Rays Following the Positron Decay of Ga^{65}. J. F. FRIICHTENICHT AND L. A. BEACH, *U. S. Naval Research Laboratory.*—Thick targets of purified natural zinc have been bombarded by 1.9 Mev protons for thirty-minute periods. The most prominent activity in the residual nuclides produced is Ga^{65} which decays by positron emission with a half-life of 15 minutes. Levels in Zn^{65} following the positron decay have been studied by observing, with a 3-in.×3-in. NaI scintillator, gamma rays that are coincident with positrons detected by a thin Pilot B plastic scintillator. Previous investigation[1,2] of levels in Zn^{65} excited by the $Cu^{65}(p,n)Zn^{65}$ reaction reported the following transitions: 54, 88, 119, 155, 209, and 860 kev. In the present experiment the following transitions have been observed: 114, 154, 210, 640, 745, 880, and 1060 kev with indications of one or more transitions below 100 kev. Results of coincidence measurements between gamma rays will also be reported.

[1] E. M. Bernstein and H. W. Lewis, Bull. Am. Phys. Soc. Ser. II, 2, 60 (1957).
[2] C. F. Cook and T. W. Bonner, Phys. Rev. 94, 807(A) (1954).

VA7. Production of Ga^{74}. E. EICHLER, N. R. JOHNSON, AND G. D. O'KELLEY, *Oak Ridge National Laboratory.**—Irradiation of germanium metal containing 97.7% Ge^{74} with 14-Mev neutrons produced a radionuclide whose integral gamma-ray activity, as observed with a NaI scintillation detector, decayed with a 7.5±0.4 min half-life. The gamma-ray spectrum showed an intense 0.60-Mev line as well as transitions with energies of 0.86, 1.9, 2.3, and possibly 1.1 and 1.5 Mev. The 0.60-Mev transition corresponds to the decay of the first excited state of Ge^{74} as seen in Coulomb excitation.[1] This fact coupled with the high degree of enrichment of the target material indicates strongly that this nuclide is Ga^{74} produced by the n,p reaction of Ge^{74} and is in general agreement with Morinaga's results on the irradiation of natural germanium with fast neutrons.[2]

* Operated by Union Carbide Nuclear Company for the U. S. Atomic Energy Commission.
[1] G. M. Temmer and N. P. Heydenberg, Phys. Rev. 104, 967 (1956).
[2] H. Morinaga, Phys. Rev. 103, 504 (1956).

VA8. Nuclear Spectra of Tc^{100}. G. D. O'KELLEY, E. EICHLER, AND N. R. JOHNSON, *Oak Ridge National Laboratory.**—The gamma-ray spectrum of 16-second Tc^{100} exhibits an intense doublet of 0.542±0.006 and 0.600±0.009 Mev energy. Weaker gamma rays of 0.71, 0.81, 0.89, 1.01, 1.14, 1.31, 1.49, and 1.8 Mev, as well as unresolved low energy components, are also present. The 0.542-Mev gamma ray, which represents the decay from the first excited level of Ru^{100}, is coincident with the 0.600-Mev gamma ray and thus establishes an excited state at 1.14 Mev. Scintillation beta-ray spectra were resolved into components of 3.38±0.06 and 2.88±0.07 Mev, which decay to the ground and first excited states of Ru^{100}, respectively. A beta-ray group of about 2.2 Mev is in coincidence with the gamma-ray doublet of 0.542–0.600 Mev, as expected for the beta rays feeding the 1.14-Mev level of Ru^{100}.

* Operated by Union Carbide Nuclear Company for the U. S. Atomic Energy Commission.

VA9. Beta Decay of Ag^{111}. R. L. ROBINSON AND L. M. LANGER, *Indiana University.**—The relatively high comparative lifetime ($\log ft = 7.8$) of the low energy inner beta group of Ag^{111} suggests that interference might result in a spectrum with a nonstatistical, nonunique shape. The beta spectrum was investigated with a 4π beta-ray scintillation spectrometer. This group was separately observed by counting only the beta rays in coincidence with the 340-kev gamma rays. The Fermi plot is not linear. The shape correction factor decreases by ~17% in the energy range 80 to 600 kev. A satisfactory once forbidden theoretical shape correction factor can be obtained by using only S and T interactions. Beta rays were also recorded in coincidence with the 247-kev gamma rays. Because of distortion arising mainly from beta rays coincident with Compton electrons produced by scattered 340-kev gamma rays, no definite conclusion can be made about the shape of this spectrum. The end-point energies of the groups in coincidence with the 340- and 247-kev gamma rays are, respectively, 690±13 kev and 793±15 kev. The end-point energy of the ground state transition was measured as 1044 ±20 kev. By comparison of total decay energies, it is deduced that both gamma rays terminate at the ground state of Cd^{111}, in agreement with the decay scheme proposed by Johansson.[1]

* This work was supported by the joint program of the Office of Naval Research and U. S. Atomic Energy Commission and by a grant from the Research Corporation.
[1] S. Johansson, Phys. Rev. 79, 896 (1950).

VA10. The Radioactivity of Sb^{118}. C. L. MCGINNIS AND D. N. KUNDU, *National Research Council.*—The radiations of the 5 hour Sb^{118} have been investigated using a magnetic lens spectrometer and scintillation counters. Two gamma rays were found with the lens spectrometer with energies 0.040

Mev (ce_{LM} only observed) and 0.256 Mev, (K/LM=5.4, α_K=0.039). The ratio ($ce_{LM}0.040\gamma$)/($ce_K0.256\gamma$) was measured to be 0.5. With a scintillation counter 1.03- and 1.22-Mev gamma rays were observed and found to be equally intense. Possible 1.29- and 2.25-Mev crossover gamma rays were not observed. With a well-type crystal the following sum peaks were found: 0.28, 0.31, 1.31, 1.47, 2.23, and 2.52 Mev. From single crystal and gamma-gamma angular correlation counting an upper limit of 0.4% is placed on the occurrence of positrons. In the decay of the 3.5 min Sb^{113} the 1.22-Mev gamma was observed but the 1.03-Mev gamma was not. In the 3.5 min activity the ratio of the 1.22 gamma to the annihilation radiation was observed to be 0.027.

VA11. Charge Spectrometry for Xe^{133}. ARTHUR H. SNELL AND FRANCES PLEASONTON, *Oak Ridge National Laboratory.*—The distribution in charge of the Cs^{133} ions formed by radioactive decay of the 5.3-day activity in Xe^{133} consists of a decrease from charge 1 to a minimum at charge 4, followed by a rise to a peak at charge 9, and a drop-off to charge 20. The activity is known to consist mainly of β emission followed by an 80 kev gamma ray, which is internally converted in about 60% of the decays. In the charge spectrum, we ascribe the initial, decreasing part to atoms which escape internal conversion, and the main part of the distribution with the peak at charge 9 to atoms which undergo internal conversion. A comparison of the intensities in the two parts of the spectrum gives a value for the summed $K+L+M$ conversion coefficients, and this is in rough agreement with values obtained by others using different methods.

VA12. Disintegration of La^{131}. A. C. G. MITCHELL, C. B. CREAGER, C. W. KOCHER, AND H. H. HELMICK,* *Indiana University.*†—The disintegration of La^{131} (19.5 hours) has been investigated with the help of a magnetic lens spectrometer and a scintillation spectrometer. The sources were prepared by bombarding barium enriched in Ba^{134} with deuterons in the cyclotron. Suitable chemical separations were made. Gamma rays occur at 862, 558, 481, 367, 300, 219, and 95 kev. There is also possible a weak line near 1.5 Mev. The gamma rays at 219, 300, and 367 kev are in coincidence. Many of the gamma rays internally converted, the strongest being that at 481 kev which has a K/L ratio ~6. There appear to be no positrons. A level scheme is proposed.

* Now at the Los Alamos Scientific Laboratory.
† Supported by the joint program of the Office of Naval Research and U. S. Atomic Energy Commission.

SATURDAY AFTERNOON AT 1:45

Panel Room

(MAURICE GOLDHABER presiding)

Beta and Gamma Emitters II

W1. Radiations from I^{126}. N. R. JOHNSON AND G. D. O'KELLEY, *Oak Ridge National Laboratory.**—The radiations emitted by 86-sec I^{126} have been studied with single-crystal and coincidence scintillation spectrometers. The spectrum obtained with a 3-in.×3-in. NaI crystal spectrometer showed gamma rays with energies of 3.18, 2.84, 2.61, 2.32, 1.89, 1.55, 1.32, 0.870, 0.493, 0.388, 0.270, and 0.210 Mev. Of these, the 1.32-Mev gamma ray was most intense. Using an anthracene crystal spectrometer two high-energy beta rays were found with energies of 5.6±0.1 and 7.0±0.1 Mev. In coincidence with the 1.32-Mev gamma-ray peak were beta rays of 5.60 ±0.15 and 4.23±0.20 Mev and possibly a third component at about 2.7 Mev. Also coincident with this prominent peak at 1.32 Mev were gamma rays of 0.19, 0.28, 0.39, 0.56, 0.87, and 1.32 Mev, the last of which is the most intense. Disagreeing somewhat with earlier experiments,[1] the above data indicate that the first two excited states in Xe^{126} are at 1.32 and 2.64 Mev with a pair of 1.32-Mev gamma rays involved in the cascade process. Implications of these measurements will be discussed.

* Operated by Union Carbide Nuclear Company for the U. S. Atomic Energy Commission.
[1] M. McKeown and S. Katcoff, Phys. Rev. 94, 965 (1954).

W2. Radioactive Sm^{145} and Pm^{145}.* W. E. CAREY, R. P. SULLIVAN, M. R. BHAT, AND M. L. POOL, *The Ohio State University.*—Samarium oxide enriched to 85.7% in isotope of mass number 144 was irradiated in the MTR reactor for two months. Scintillation spectrometer analysis of the resulting Sm^{145} radiations indicate the following: The pile absorption cross section of Sm^{144} is in the neighborhood of 0.03 barn; the ratio of the probability of L- to K-capture for Sm^{145} is 2.0; and α_K for the 61.3-kev γ ray associated with the decay of Sm^{145} is 5.7. Cauchois spectrographs revealed the presence of Nd x-rays, thus indicating that the Pm^{145} daughter for Sm^{145} also decays by electron capture. Ion-exchange column separations of the irradiated Sm^{144} yielded samples of Pm^{144}, the half-life of which appears to be several years. The only radiations associated with the decay of Pm^{145} are the Nd x-rays and a 73-kev γ ray having an α_K of 5.4. The ratio of L- to K-capture probability is 1.8. The decay scheme for Pm^{144} is similar to that previously determined for Sm^{145}. No positron emission from either Sm^{145} or Pm^{145} could be detected.

* This work was partially supported by the OSU Development Fund and the Air Force OSRD.

W3. Decay of Pm^{150}. VERA K. FISCHER AND EDWARD A. REMLER, *Columbia University and Brookhaven National Laboratory.**—The total decay energy of Pm^{150} previously determined to be 5.3±0.1 Mev[1] has been found to disagree badly with predictions based on empirical relations between decay energy and nucleon number.[2] Therefore, the gamma rays emitted in the decay of Pm^{150} have been studied with a 100-channel pulse-height analyzer-scintillation spectrometer at Brookhaven National Laboratory. The following gamma rays were observed: 2.75±0.05, 1.95±0.05, 1.68±0.03, 1.33±0.02, 1.17±0.01, 0.82±0.01, and 0.34±0.01 Mev. Gamma rays may also be present in low abundance at 0.70 ±0.05, 0.57±0.04, and 0.40±0.04 Mev. The 3.0±0.1 Mev gamma ray previously observed was not seen. On the basis of coincidence studies and relative abundances, a new decay scheme is proposed involving levels in Sm^{150} at 0.337, 1.17, 1.74, 2.00, and 3.08 Mev. The total decay energy of Pm^{150} on the basis of this decay scheme and the previously determined values of the maximum beta-ray energies[1] is 5.04±0.05 Mev.

* This work was partially supported by the U. S. Atomic Energy Commission.
[1] Vera Kistiakowsky Fischer, Phys. Rev. 96, 1549 (1954).
[2] Kay Way (private communication).

W4. A Re-Evaluation of the Beta and Gamma Energies from Ho^{166}, Nd^{147}, and Sm^{153}. J. M. CORK, M. K. BRICE, R. G. HELMER, AND R. M. WOODS, JR., *University of Michigan.**—Using enriched sources of Ho^{165}, Nd^{146}, and Sm^{152} strong specimens of Ho^{166}, Nd^{147}, and Sm^{153} were made by neutron capture. Studies of the strong sources by both magnetic and scintillation spectrometers showed the existence of some gamma rays not previously reported, more exact values for the low-energy gamma rays, and better resolution of the components of the beta spectra. In Ho^{166} gamma rays occur at 80.25, 970, 1377, 1540, and 1620 kev, and the maximum beta energies are 1839, 1758, 869, 380, and 220 kev. Nd^{147} yields gamma rays at 91.3, 120.6, 198.2, 277.0, 321, 400, 441, 533, 597, and 688 kev, with beta components at 812, 380, and 230 kev. In Sm^{153} gamma rays are found at 69.8, 103.5, and 173.6 kev and beta components at 813, 710, and 640 kev. A level scheme is presented for each nucleus that is in complete agreement with observed data.

* Work supported jointly by the Office of Naval Research and the U. S. Atomic Energy Commission.

W5. The Radiations of Os^{185}.† S. S. MALIK* AND AMBUJ MUKERJI,‡ *Bartol Research Foundation.*—The radiations of Os^{185} have been examined in a thin magnetic lens beta-ray spectrometer and in coincident scintillation spectrometers. By these means, gamma rays of energies 75, 120, 158, 233, 593, 643, 870, and 878 kev have been resolved, revealing excited energy levels of the residual nucleus, Re^{185}, at 120, 278, 643, 718, 870, and 878 kev. Internal conversion coefficient measurement showed the 643-kev gamma ray to be predominantly $E2$ with a slight mixture of $M1$. Search for positrons was made by observing gamma-gamma coindidences with the counters placed at 180° and 90°. An upper limit of 10^{-9} positron per disintegration could be set.

† Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
* Permanent address: Muzaffar Nagar (U.P.) India.
‡ On leave of absence from the Tata Institute of Fundamental Research, Bombay, India. Present address: A and M College of Texas.

W6. Gamma Rays of Au^{198}. WALTER R. KANE AND GUY T. EMERY, *Harvard University.**—The γ-ray spectrum of Au^{198} has been reinvestigated in a high-resolution β-ray spectrometer with thin photoelectric converters. Hamermesh and Smither[1] have examined this spectrum with a bent-crystal spectrometer; they report a doublet with energies 671.1 and 678.9 kev and intensity ratio ~3:1, and evidence for a similar doublet near 1088 kev. We find no evidence for doublet structure. We see one line at 675.4±0.4 kev and one line 1086.6±0.6 kev. The full momentum widths of our lines at half-height for our thinnest converter are 0.48% (4.1 kev) for the lower line and 0.28% (3.7 kev) for the higher. According to our data, if the line at 675 kev had a satellite with 7.8 kev more energy the satellite intensity would be less than 1/70 that of the principal line; if the satellite had 7.8 kev less energy its relative intensity would be less than 1/30. For a satellite with the same energy difference from the 1087 kev line the corresponding upper limits are 1/12 and 1/10.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] B. Hamermesh and R. K. Smither, Bull. Am. Phys. Soc. Ser. II, 2, 232 (1957).

W7. Capture Gamma Rays in Hg^{200}.† RALPH E. SEGEL,* *Aeronautical Research Laboratory.*—The gamma-ray cascades following thermal neutron capture in mercury were observed using a three-crystal pair spectrometer in coincidence with a 3 in.×3 in. NaI(Tl) crystal. The predominant capture in natural mercury is in Hg^{199} leading to a state at about 8.05 Mev in Hg^{200}. The following cascades were found (energy in Mev): 6.44−1.59, 6.44−1.22−0.37, 6.31−1.73, 6.31−1.36−0.37, 5.96−1.73−0.37, and 5.67−2.02−0.37. These experimental results show some discrepancies with the high resolution singles spectrum,[1] and also with the decay of Tl^{200}.[2] The decay scheme is significantly different from that inferred from the singles spectrum.

† Work performed under the auspices of the U. S. Atomic Energy Commission.
* Guest scientist at Brookhaven National Laboratory.
[1] Ayasevich, Groshev, and Demidov, Conference of the Academy of Sciences of the USSR on the Peaceful Uses of Atomic Energy, July, 1955.
[2] C. J. Herrlander and T. R. Gerholm, Nuclear Phys. 3, 161 (1957).

W8. Half-Lives of Lead 203 and Lead 204. A. A. BARTLETT* AND GLEN REBKA, *Harvard University.*—Two foils of radiolead were bombarded with an internal beam of approximately 0.2 microampere-hours of protons at approximately 35 and 30 Mev respectively in the Harvard cyclotron. The lead activity was separated from the bismuth in an ion-exchange column and the activity of the lead fractions was measured with a double ionization chamber.[1] Two sources from the first bombardment showed a 67-min activity (Pb^{204}) that quickly became less than a 52-hr activity (Pb^{203}) which was then measured over an intensity factor of 4 for one sample and 20 for the other. A weighted least-squares analysis gave the half-life (Pb^{203}) to be 52.1±0.2 hr. In the source from the second bombardment it was possible to follow the 67-min decay over an intensity factor of 500 before its activity became equal to that of the Pb^{203}. A weighted least-squares analysis of the separated Pb^{204} activity yielded a half-life of 66.9±0.1 min.

* On leave from the University of Colorado.
[1] Bainbridge, Goldhaber, and Wilson, Phys. Rev. 90, 430 (1953).

W9. Energy Release from the Decay of Fission Products and the Antineutrino Spectrum. J. F. PERKINS, *Lockheed Aircraft Corporation*, AND R. W. KING, *Purdue University.**—A calculation of energy release from the decay of U^{235} fission products has been made by examining in detail the individual decay schemes of the many nuclei involved. The very good agreement with experiment that has been obtained for times after shutdown $>10^2$ sec speaks strongly for the validity and completeness of the input data for nuclei with half-lives $>10^2$ sec. We are hence in a position to plot the distribution of beta-decay end points with considerable accuracy for $E_{\beta\max} \lesssim 4$ Mev. Comparisons are made with the assumed distribution of Muehlhause and Oleksa[1] used in the calculation of the antineutrino flux from a reactor. Antineutrino energy spectra are also investigated as a function of operating time and time after shutdown.

* Assisted in part by contract with the U. S. Air Force Office of Scientific Research.
[1] C. O. Muehlhause and S. Oleksa, Phys. Rev. 105, 1332 (1957).

W10. Electric-Monopole Directional-Correlation Experiments.* E. L. CHURCH, *Frankford Arsenal,*† M. E. ROSE, *Oak Ridge National Laboratory*, AND J. WENESER, *Brookhaven National Laboratory.*—Angular-correlation experiments involving conversion electrons are sensitive to small admixtures of electric-monopole ($E0$) transitions. The coefficient of $P_2(\cos\theta)$ in the directional-correlation function involving a mixed $E0+M1+E2$ transition contains an interference term between the $E0$ and $E2$ conversion electrons, which is proportional to the ratio of the $E0$ and $E2$ nuclear matrix elements. Measurement of this coefficient provides a sensitive means for determining both the magnitude and phase of the monopole matrix element relative to the $E2$ gamma-ray matrix element. The effect on the directional-correlation function between such K-conversion electrons and a coincident gamma ray is calcur lated explicitly. Specific numerical results are given fo-Pt($Z=78$) over a range of energies. The sensitivity of the proposed directional-correlation experiment is illustrated with reference to the particular case of the 2+→2+→0+ cascade

in Pt^{198}. It is found that the correlation function is insensitive to the effect of the new nuclear matrix elements for $M1$ and $E2$ internal conversion introduced by the finite nuclear size, but very sensitive to small monopole admixtures.

* Work supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
† Guest Scientist at Brookhaven National Laboratory.

W11. Interpretation of Angular Correlation Experiments. P. S. JASTRAM, *Ohio State University*, AND G. T. WOOD* AND J. P. HURLEY, *Washington University*.—A consequence of the occurrence of multipole mixtures in electromagnetic transitions between nuclear states is that an experimental determination of the angular correlation between sequential gamma rays may fail to yield a unique assignment of spins and multipole orders. In each case it has been necessary to investigate all the likely combinations of spin assignments and multipole mixtures in order to ascertain which were consistent with a particular experimental result. Displaying the results of angular-correlation theory in the form of a family of parametric graphs of the dependence of the correlation expansion coefficients on spin and multipole mixture values reduces the analysis to reading off the assignments which are consistent with a single experimentally determined point. An advantage of the method is that by inspection conclusions may be drawn as to whether and to what degree a measured correlation is ambiguous in determining the spins, multipoles, and mixing ratios; the various possible choices are immediately evident. It appears that the graphical representation will be simple enough to be useful only if at least one of the radiations can be assumed to be a pure multipole; only such cases are considered.

* Now at the Argonne Cancer Research Hospital, Chicago, Illinois.

W12. The Use of Polarization-Direction Correlation to Determine Spins and Multipole Mixtures.* G. T. WOOD,† *Washington University*, AND P. S. JASTRAM, *Ohio State University*.—If in a polarization-direction correlation measurement involving cascaded gamma rays, one of which is a mixed-multipole transition, the mixed radiation is detected in the polarization-sensitive counter, the dependence of the degree of polarization on the mixing ratio is in general different from that of the direction angular correlation. Consequently, in cases in which the direction correlation corresponds to more than one possible choice of spin and multipole mixture assignments, a polarization-direction correlation measurement will distinguish between the possible assignments and establish the correct one. The results of the polarization-direction correlation theory may be expressed in the form of a set of parametric plots similar to those for direction angular correlation. Of those worked out so far, there appears to be no case in which the combined direction- and polarization-direction correlations fail to yield a unique assignment for spins and multipole mixtures; in particular, the polarization measurement is decisive for establishing (or refuting) the frequently encountered 0-2-4 spin assignment, which cannot be established by direction correlation measurements alone.

* Supported by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.
† Now at the Argonne Cancer Research Hospital, Chicago, Illinois.

SATURDAY AFTEKNOON AT 1:45

Governor Clinton

(S. A. SCHAAF presiding)

Fluid Dynamics

X1. Rayleigh's Problem and Kinetic Theory of Gases.* E. A. JACKSON AND E. P. GROSS, *Brandeis University*.—The problem of an infinite plate in a gas set impulsively into uniform motion along its plane is studied. We seek solutions of the linearized Boltzmann equation appropriate to the case when the speed of the plate is less then the sound speed. The accurate description of the gas depends on distinguishing between the molecules which are impinging on, or leaving, the plate. In order to do this we use Yoon's method of half-range distribution functions previously used to study the Couette flow problem for all values of density.[1] This method enables us to satisfy the boundary conditions and thereby obtain exact results for both long and short times. With the problem formulated in terms of half-range distribution functions, it is necessary to use only a few velocity polynomials to obtain excellent results. Comparing the results with those based on the Navier-Stokes theory and by Grad's thirteen moment method,[2] it is found that they become inaccurate for times less then the collision period.

* Work supported by Office of Scientific Research, U. S. Air Force.
[1] Gross, Jackson, and Ziering, Ann. Phys. 1, 141 (1957).
[2] H. Yang, and L. Lees, J. Math. Phys. 35, 195 (1956).

X2. Spectrum of Turbulence in the Universal Range at Huge Reynolds Numbers.* ROBERT H. KRAICHNAN, *New York University*.—Previous work on high Reynolds number isotropic turbulence[1] is extended to include the dissipation sub-range. It is found that for $k_0 \ll k \ll Rk_0$ the time-auto-correlation function of a velocity-field Fourier mode is $r(k,\tau) \approx J_1(2v_0 k\tau)/(v_0 k\tau)$, where $k_0 = \epsilon/v_0^3$, ϵ = dissipation-rate/unit mass, v_0 = rms velocity in any direction, $R = v_0/k_0\nu$, and ν = kinematic viscosity. For $R^{\frac{1}{2}} \gg 1$, it is found that this k range includes both inertial and dissipation sub-ranges and that in it the one-dimensional energy-spectrum/unit mass $E(k)$ is fixed by $2\nu k^2 E(k) \approx k \int\int [k^3 a(\Delta) E(p) - p^3 b(\Delta) E(k)] \times E(q)\theta(\Delta) p^{-1} q^{-1} dp dq$, where integration is over all points such that p, q, and k can form legs of a triangle Δ, a and b are complicated, essentially positive, trigonometric functions of the angles of Δ, and $\theta(\Delta) = \int_0^\infty r(k,\tau) r(p,\tau) r(q,\tau) d\tau \geq 0$. The solution is of the form $E(k) \approx (\epsilon\nu_0)^{\frac{1}{2}} k^{-\frac{1}{2}} f(k/k_d)$, where $k_d = R^{\frac{1}{2}} k_0$ and f is a dimensionless, universal function normalized by $\int_0^\infty y^{\frac{1}{2}} f(y) dy = \frac{1}{2}$. For $k \ll k_d$, $f(k/k_d) \approx$ const, yielding the inertial sub-range spectrum previously described.[1] For $k \gg k_d$, $f(k/k_d) \sim (\text{const})(k/k_d)^{5/2} \exp[-(\text{const})k/k_d]$. The complete solution may be computed by an iteration method. Extension of the theory to $k \gg Rk_0$ gives $E(k) \propto k^3 \exp[-(\text{const})k]$, indicating the existence of mean-square velocity derivatives of all orders.

* Supported by the Geophysics Research Directorate, Air Force Cambridge Research Center.
[1] R. H. Kraichnan, Bull. Am. Phys. Soc. Ser. II, 2, 307 (1957).

X3. (Abstract transferred to Session SP (see abstract SP4).

X4. Hypersonic Shock Tunnel for Investigating Flow Over Bodies with Real Gas Effects. H. T. NAGAMATSU AND R. E. GEIGER.—For flight Mach numbers greater than 10 the air can no longer be considered as being a simple mixture of diatomic oxygen and nitrogen. The effects of dissociation, ionization, and chemical reaction in air become appreciable at the high stagnation temperatures produced by bodies moving at hypersonic speeds. In order to investigate the real gas effects upon the aerodynamic characteristics of the flow over bodies, a hypersonic shock tunnel was developed. It is a research tool for producing high Mach numbers and stagnation temperatures simultaneously, similar to those encountered by the ballistic missiles in atmospheric flight at high altitudes. The real gas effects upon the shock wave shape and the detachment distance for blunt bodies are presented for a Mach number range of approximately 10 and above, at high stagnation temperatures. For these bodies the photographs showing the luminous region of the heated air are presented. The preliminary results indicate that the real gas effects move the detached shock wave closer to the body. By means of piezoelectric pressure gauges, the pressure distribution over simple three-dimensional blunt bodies were determined for different stagnation temperatures and Mach numbers. The shock wave shape and approximate boundary layer growth on a flat plate are presented.

X5. Production of High Velocity Shock Waves and their Interaction with Magnetic Fields. G. S. JANES, *Avco Research Laboratory.*—Highly ionized hydrogen (or deuterium) in a 4-in. diameter cylindrical Pyrex chamber is driven radially inward toward the axis by a fast rising exterior axial magnetic field.[1] The electromagnetic analog of a shock wave is set up in a nonlinear transmission line with inductive and resistive elements by the use of a high voltage capacitive energy energy storage system and a spark gap, Inth is manner a field of 12 000 gauss is produced behind the gas in less than 0.2 μsec. The experimental arrangement easily permits optical and magnetic observation. Shock wave velocities between 15 and 18 cm per μsec have been observed in H_2 and D_2 at pressures of 0.15 mm Hg and above using smear cameras and photomultipliers. Assuming momentum conservation and a small skin depth in the gas, these results are in substantial agreement with theoretical predictions. Velocities in excess of 25 cm/μsec have been observed at lower gas pressures, but their interpretation as shock waves is not clear. Experiments will be described on the interaction of these shock waves with enclosed magnetic fields.

[1] G. S. Janes, 10th Annual Gaseous Electronics Conference, Cambridge, Massachusetts (1957).

X6. Reflection of Shock Waves from an Orifice at the End of a Duct.† GEORGE RUDINGER, *Cornell Aeronautical Laboratory.*—The flow conditions behind the reflected wave generally have been computed under the assumption that the boundary conditions at the orifice for nonsteady flow are the same as those for steady flow. One obtains, then, a reflected wave that is either a simple expansion wave or a shock wave depending on the strength of the incident shock and on the orifice size. Experimental observations show that the reflected wave always consists of a shock front followed by an expansion wave. Interaction of these waves produces a pressure pulse which may considerably exceed the maximum pressure computed in the conventional manner. This "overshoot" may be computed on the basis of a few plausible assumptions about the effective reflection conditions at the orifice. It is particularly pronounced if the pressure change across the entire reflected wave is zero and may reach a maximum of almost 40% of the pressure ahead of the incident shock wave when the latter has a pressure ratio of about 2.3. Results of shock tube experiments in which the pressure variations across the incident and reflected waves are recorded at various distances from the orifice and for different shock strength and orifices agree well with the calculated overshoot pressures.

† Work carried out under the auspices of Project SQUID, sponsored by the Office of Naval Research.

X7. Mach Reflection Studies with the Hydraulic Analogy. E. V. LAITONE, *University of California, Berkeley.*—By means of the shallow water hydraulic analogy an experimental study was made of the Mach reflections produced by a symmetrical wedge moving at supersonic speeds near a plane wall. It was found that at certain conditions the incident wave and the normal wave became very straight, while the reflected wave completely disappeared. The same results were also obtained for the flow between two parallel wedges. A comparison was then made with the phenomenon exhibited by a solitary hydraulic wave moving through shallow still water. Although the appearance of the regular reflection and the Mach-type reflection seemed to provide some apparent similarities to the gas dynamics case or the hydraulic analogy, the actual behavior was radically different because of the essentially finite width of the solitary wave. It is pointed out how this difference could explain the behavior of Mach reflection tests performed with certain types of finite wave generators.

X8. Exact Solution of the Impulsive Motion of a Flat Plate in Magnetohydrodynamics. C. C. CHANG AND J. T. YEN, *University of Minnesota.*—The velocity and induced magnetic fields due to impulsive motion of an infinite flat plate in a viscous, incompressible and electrical conducting fluid in the presence of an applied magnetic field are investigated. The exact differential equations governing the magnetohydrodynamic fields are dealt with in the investigation. Exact solutions for the velocity and induced magnetic fields are found by using Laplace transformation and employing appropriate boundary and initial conditions. Salient mathematical features of the problem are linearity and constancy in coefficients of the governing equations. The physical interpretations of the resulting exact solutions, however, reveal important coupling effects on friction and magnetic induction when both electromagnetic and hydrodynamic fields are present.

X9. Theoretical Investigation of the Flow-Field about Blunt-Nosed Bodies in Supersonic Flight.* R. VAGLIO-LAURIN AND A. FERRI, *Polytechnic Institute of Brooklyn.*—A numerical method for obtaining the solution of the inverse problem of the flow behind a given detached shock to any desired accuracy is presented. The cases of zero and small incidence are considered. The combinations of sets of such

solutions satisfying prescribed boundary conditions (body shapes) is described. Particular attention is devoted to the analysis of the sonic and subsonic region of the flow field. Convergence and stability of the stepwise integration from the shock in the elliptic region are discussed. Numerical examples are also included.

* The investigation has been carried out at the Gruen Applied Science Laboratories, Inc., under contract with the General Electric Company.

X10. Two-Dimensional Stagnation Point Flow of an Incompressible, Viscous, Electrically Conducting Fluid in the Presence of a Magnetic Field. J. L. NEURINGER AND W. MCILROY, *Republic Aviation Corporation.*—When a blunt body moves through the atmosphere at high hypersonic speeds, there exists a cap of ionized gas between the detached shock and the nose of the body. It was considered possible that by impressing a magnetic field out of the nose of the body and into the conducting gas some beneficial effects could be derived from this region. In order to demonstrate this fact theoretically, consideration was given to the well-known problem of the two-dimensional stagnation point flow on an infinite flat plate, modified in two ways: (1) the fluid was assumed incompressible but conducting, and (2) impressed on the fluid was an external parallel magnetic field normal to the plate. From the resulting analysis of the hydromagnetic interaction, it appears that a considerable reduction in heat transfer and skin friction may be possible with reasonable values of the applied magnetic intensity and electrical conductivity of the fluid. The reduction in heat transfer and shear stress at the wall is found to be a function of a nondimensional parameter $h^2(O)/\gamma$ defined in the talk.

X11. High-Speed Flow of Gas Around Blunt Bodies. HYMAN SERBIN, *The Rand Corporation* (introduced by E. H. Vestine).—A number of results derived by the author in earlier studies are here collected and presented in a unified rational theory. The analysis is carried out for the limiting case where the ratio of specific heats is near unity and the free-stream Mach number (steady flow) is very large. Both these parameters are combined into a single parameter, the density ratio across a normal shock. The results of the theory agree well with test data, both with respect to shock location and shock shape for test Mach numbers of order 6 and presumably higher. A simple extension (method of conjunction) extends the agreement throughout the entire range of supersonic Mach numbers.

Business Meeting of the Division of Fluid Dynamics

(To be held during Session X at whatever time the Chairman chooses.)

SATURDAY AFTERNOON AT 1:45

Empire Suite

(V. BARGMANN presiding)

Theoretical Physics VI: Relativity and Collision Processes

XA1. Conservation Laws in General Relativity. J. GOLDBERG, *Aeronautical Research Laboratory.*—It is well known that in general relativity one can construct a quantity with mixed indices who ordinary divergence vanishes.[1] Since the properties of this quantity can be derived from the covariance of the theory,[2] the vanishing divergence is called the conservation law for energy and momentum. Indeed, because of these relations one can derive the equations of motion for point particles in a gravitational field.[3] Recently Laudau and Lifschitz[4] have obtained a symmetric quantity which has a vanishing divergence. Based on their work, it is possible to construct an infinite number of symmetric quantities as well as mixed quantities. However, all of the mixed quantities can be related to the covariance of the theory and lead to the same physical results. The symmetric quantities may be constructed because of the symmetric nature of the metric tensor and do not lead to the same physical results. However, the content of the symmetric quantity formed by Laudau and Lifschitz is the same as that obtained from the mixed quantities.

[1] P. G. Bergmann, *Introduction to the Theory of Relativity* (Prentice-Hall, Inc., New York, 1947).
[2] P. G. Bergmann, Phys. Rev. **75**, 680 (1949).
[3] L. Infeld, Revs. Modern Phys. **29**, 398 (1957).
[4] Laudau and Lifschitz, *The Classical Theory of Fields* (Addison-Wesley Publishing Company, Inc., Cambridge, 1951).

XA2. Constitutive Equations for Moving Anisotropic Media. L. DIESENDRUCK, *University of Rhode Island.*—Minkowski's equations relating B, E, H, and D for moving isotropic media are extended to give similar equations for moving anisotropic media. Boundary conditions are found for the fields. The results are applied to the determination of the fields of a moving charge in an anisotropic medium.

XA3. Structure of Particles in Linearized Gravitational Theory.* RAINER SACHS AND PETER G. BERGMANN, *Syracuse University.*—We have attempted to examine the invariant character of restrictions imposed on singularities of the gravitational fields in the EIH theory of motion in general relativity. So far we have succeeded in providing a complete classification of singularities that can occur in the linearized theory only, in terms of properties that are invariant under Lorentz and "gauge" transformations (the latter designation refers to linearized curvilinear coordinate transformations). Except for several explicitly known solutions, which have previously been considered by Havas, all solutions can be derived from a "super-metric" corresponding to the Hertz potential of electrodynamics. One method of classification is in terms of gauge invariant integrals over spatial closed surfaces completely surrounding the particles.

* Research supported by National Science Foundation and by Aeronautical Research Laboratory, WADC.

XA4. Classification of Particles by Means of the Curvature Tensor.* PETER G. BERGMANN AND RAINER SACHS, *Syracuse University.*—In the course of the examination of singular solutions of the linearized field equations described in the preceding abstract we also examined the characteristics of the curvature tensor of the gravitational field surrounding each type of singularity. At any given instance in time the comoving frame of reference is preferred, and we have formed

the curvature tensor components of fields that are static near the particle in that preferred frame. Using the same approach as Petrov[1] and Pirani,[2] we found that there are two essentially different types of singularity, corresponding roughly to electric and magnetic sources, respectively, of static electromagnetic fields. Though this classification cuts across the lines established in the preceding abstract, an equivalence between the results of the two approaches is easily established.

* Supported by National Science Foundation and by ARL, WADC.
[1] A. Z. Petrov, Sci. Not. Kazan State Univ. 114, 55 (1954).
[2] F. A. E. Pirani, Phys. Rev. 105, 1089 (1957).

XA5. Observation of Distant Events in General Relativity. E. NEWMAN, *University of Pittsburgh*, AND J. GOLDBERG, *Aeronautical Research Laboratory*.—Any description of astronomical events assumes implicitly the use of a coordinate system. In general relativity any coordinate system is acceptable. The question arises as to how one may correlate observational data with predictions of the theory.[1] The only meaningful coordinate system that can be established is a set of events which can be given a set of numbers which are arbitrary except for precedence and continuity. We propose to use this type of description in the following way. The events we wish to describe will be the positions of a body moving through space-time. The events, in terms of which this motion will be described, will be the emission of two light rays, with a small angle between them, directed towards an observer. The numerical value given to this event will be the proper perpendicular distance between the two null rays when they reach the observer. This perpendicular distance, which is known as geodesic deviation in Riemannian geometry, satisfies a linear differential equation. We have applied this method to planetary motion without recourse to a correspondence with Newtonian mechanics.

* This work was supported in part by the Wright Air Development Center through Ohio State University.
[1] For a fuller description of this problem, see E. P. Wigner, Revs. Modern Phys. 29, 255 (1957).

XA6. Construction of Observables in General Relativity.* ARTHUR B. KOMAR, *Syracuse University*.—If the field equations of general relativity are satisfied, then one can construct at each world point exactly four scalars A^i as the roots of eigenvalue problems involving the curvature tensor. If these four scalars are algebraically independent of each other, they can serve as a uniquely defined (local) "canonical" coordinate system. The components of the corresponding canonical metric tensor are individually invariants; if they are given as functions of the four A^i, the Riemannian manifold is thereby uniquely characterized. Hence these ten functions of four arguments represent a complete system of observables. This system is still highly redundant: In addition to the usual ten field equations, the components of the canonical metric tensor satisfy four additional differential equations, "coordinate conditions" that assure the canonical character of the coordinate system A^i. The Cauchy problem for these fourteen differential equations will be discussed. Its solution will yield a complete set of independent observables.

* Supported by AFOSR and by NSF.

XA7. Quantum-Mechanical Model of Relativistic Behavior. J. C. FISHER, *General Electric Research Laboratory*.—A periodic perturbing potential with amplitude $2V_0$ and appropriate wavelength provides a gap of forbidden energies for fermions at the Fermi level. Near the gap, the perturbed energy is

$$E(k)=mc^2/2+\hbar^2k_1^2/2m\pm(\hbar^2c^2k_1^2+m_0^2c^4)^{\frac{1}{2}},$$

if one writes $\hbar k_f/m=c$, $V_0=m_0c^2$, $k_1=k-k_f$. In the limit $m\to\infty$ with $\hbar k_f/m$ remaining constant, this is just the relativistic relationship $E=m_0c^2(1-v^2/c^2)^{-\frac{1}{2}}$ with the origin of E at the center of the gap and with $v=\hbar^{-1}dE/dk$. The natural appearance of the relativistic relationship for freely moving wave packets in this simple classical quantum-mechanical system suggests that the masses of the familiar particles of physics may be interpreted as effective masses. The universe then would consist of a dense sea of fermions, most of which are out of sight in a collective bound state similar to the superconducting state. A finite density of fermions below the gap would provide a high-frequency cutoff for the electromagnetic field and a possible mechanism for gravitation.

XA8. Time-Independent Nonrelativistic Collision Theory.* E. GERJUOY, *University of Pittsburgh*.—Arbitrarily complicated rearrangement collisions describable by the time-independent nonrelastivistic Schrödinger equation have been treated in a wholly time-independent framework, without explicit reference to transition probabilities. Introducing a generalized probability current operator for many-particle systems, the current flow at large distances can be computed in complete analogy with one-particle scattering. This procedure leads to the same formal expressions for reaction rates as are obtained from more conventional formulations; it is an immediate consequence of the asymptotic behavior of the Green's function that the matrix elements $\Psi_f^{(-)*}V_i\psi_i=\psi_f^*V_i\Psi_i^{(+)}$ yield the scattering amplitude $A(i\to f)$, and that $\Psi_f^{(-)}$ is a solution with incoming scattered waves. Moreover the time-independent formulation avoids perplexities associated with the necessity for computing transition probabilities from projections on sets of nonorthogonal states. In the reaction $a+b\to c+d+e$ for instance it turns out automatically, without projecting the solutions on plane wave states, that coincidences are observed in counters placed at large distances r_c, r_d, r_e only when r_c, r_d, r_e are in the ratios of the classical velocities of c,d,e; here c,d,e are a rearrangement of the particles contained in a,b. Our procedures are not without their own difficulties however; these and other problems will be discussed.

* This work was supported in part by the Office of Naval Research.

XA9. Born Series and Dispersion Relations in Nonrelativistic Quantum Theory. A. KLEIN, *University of Pennsylvania*, AND C. ZEMACH, *University of California*.—Potential scattering of a nonrelativistic particle is examined with the aid of the Born series for the Green's function and the scattering amplitude. For a wide class of potentials, such series are shown to converge absolutely at sufficiently high incident energies and their values are approximated by their leading terms. These and related results provide a simple mathematical basis for the derivation and extension of previously given nonrelativistic dispersion formulas[1] with less restrictive hypotheses. Dipersion relations for fixed momentum transfer and for fixed scattering angle are treated.

[1] N. N. Khuri, Phys. Rev. 107, 1148 (1957); D. Y. Wong, Phys. Rev. 107, 302 (1957).

XA10. Screened Coulomb Potential Phase Shifts: Low Energy Limit.* K. TOKUNAGA, *Western Reserve University*.—Numerical integrations[1] of the radial Schroedinger equation with a Yukawa potential, for electron energies of the order of 1 ev, have shown that the Born approximation does not give correct phase shifts at very low energies. The discrepancy suggested a variational approach[2]: determining the phase shifts by extremalizing the expression $k\cot\eta_l$. Applying the Born approximation at this later stage, one obtains for the low-energy limit,

$$\lim_{k\to 0}(k\cot\eta_l)=[\lim_{k\to 0}(k\cot\eta_l)]^B[1\pm\tfrac{1}{2}^{2l}(2l+1)q].$$

The superscript B refers to the first Born approximation result; q is the screening constant measured in reciprocal Bohr radii. The + sign holds for the repulsive potential, the − sign for the attractive. For the s wave ($l=0$) the expression, which is then equal to the reciprocal of the "scattering length," gives considerable improvement over the first Born approximation, which, it should be noted, yields numerically the same phase shifts for attractive and repulsive potentials.

* Assisted by the U. S. Atomic Energy Commission.

[1] Rubenstein, Huse, and Machlup, Math. Tables and other Aids to Computation 10, 30 (1956); S. Machlup, J. Chem. Phys. 24, 169 (1956).
[2] John M. Blatt and J. David Jackson, Phys. Rev. 76, 18 (1949).

Saturday Afternoon at 1:45

Boston-Washington Room

(A. S. Nowick presiding)

Metals

Y1. Peltier Effect at the Solid-Melt Interface in Some Metals. J. M. Bardeen and B. S. Chandrasekhar, *Westinghouse Research Laboratories* (introduced by P. A. Flinn).—There have recently been suggestions by Ioffe[1] and by Pfann and others[2] to use the Peltier effect at the interface between a conducting solid and its melt, in connection with solidification studies. Experiments have been done to measure directly the Peltier coefficient at the solid-melt interface in several low-melting metals. Measurable effects were observed in bismuth and cadmium, and to a lesser extent in zinc. In bismuth, the passage of current from the solid to the melt across the interface causes an absorption of heat, and the Peltier coefficient is 0.014 v. The effects in cadmium and zinc are opposite in sign to that in bismuth, and only about a quarter as large. The value obtained for bismuth agrees with that reported by Pfann,[2] but is only about half the value deduced from the thermo-electric power data of Boylston.[3] A possible explanation of this discrepancy will be discussed.

[1] A. F. Ioffe, Zhur. Tekh. Fiz. 26, 478 (1956).
[2] Pfann, Benson, and Wernick, J. Electronics 2, 597 (1957).
[3] R. W. Boylston, Phys. Rev. 30, 911 (1927).

Y2. Thermoelectric Power of Separated Lithium Isotopes.* D. J. Montgomery, R. G. Leffler, and G. M. Smith, *Michigan State University.*—The thermoelectric power S between wires of Li^6 (99.3% Li^6, 0.7% Li^7) and Li^7 (0.2% Li^6, 99.8% Li^7) was measured at temperatures T between 77 and 295°K. The value of dS/dT for Li^7 with reference to Li^6 was found to be less than $+5\times10^{-4}$ μv/(K°)^2, giving a thermoelectric force of about 15 μv between room temperature and liquid-nitrogen temperature. With the present specimens it is impossible to rule out the slight chemical impurities as the source of even this small voltage. In any event, the standard rather unsatisfactory theories of thermoelectric power indicate a difference of considerably less than 2% between isotopes in the rate of change of electron mean free path with energy.

* Supported by the Office of Ordnance Research and the U. S. Atomic Energy Commission.

Y3. Surface Structure of Field Evaporated Metal Crystals.* Erwin W. Müller and J. F. Mulson, *Pennsylvania State University.*—Low-temperature field evaporation[1] of refractory metal tips produces the cleanest surfaces of atomically perfect smoothness. Unlike the heat of vaporization of neutral atoms, the work to remove ions from a surface depends upon the crystallographic orientation because of the variation of the thermionic work function. The habit of the end form of a field evaporating metal crystal is characterized by a rounded off shape with the radius of curvature varying in the same sense as the work function of the considered region. At practically zero temperature, the actual field strength for evaporation of tungsten ions from the 111 plane is measured to be 1 billion v/cm, and for the 110 plane, 800 million v/cm, in agreement with the image force theory. High resolution ion microscope pictures of field evaporated surfaces of tungsten, rhenium, iridium, platinum, and platinum-rhodium alloy with either perfect or imperfect structures will be presented. The controlled evaporation at 21°K of individual atoms and single net planes of a platinum crystal will be shown in a short 16-mm movie film.

* Supported in part by the Air Force Office of Scientific Research and by a fellowship of the Texas Company.
[1] E. W. Müller, Phys. Rev. 102, 618 (1956).

Y4. Correlation of Annihilation Radiation from Oriented Copper Crystals.* S. Berko and J. S. Plaskett, *University of Virginia.*—According to De Benedetti *et al.*, the tail in the angular correlation of annihilation radiation from positrons in polycrystalline copper can be attributed to the sharp cutoff of the positron wave function at the "ionic radius." R. A. Ferrell states that this "excluded volume effect, being associated with the periodic lattice, should show a dependence on orientation." In particular a measurement of the momentum distribution in the (110) direction should show, besides the central parabola, subsidiary maxima at ±9.5 milliradians. We have measured the angular distribution from single copper crystals oriented in the (110), (100), and (111) directions. The apparatus was standard, each counter subtending 0.5 milliradian from the copper sample. The predicted effect has not been observed and, in fact, the shape of the tail is very similar to the polycrystalline tail, so indicating the minor importance of the high momentum components of the positron wave function. This conclusion is in agreement with a calculation by A. M. Garofalo, which indicates that the tail is predominantly due to annihilation with the d electrons. The tails in iron and cobalt are also apparently due to d electrons as can be deduced from recent experiments by S. S. Hannah and R. S. Preston.

* Supported by the Office of Naval Research.

Y5. Phase Diagram of Bismuth to 130 000 kg/cm², 500°C. F. P. Bundy, *General Electric Company.*—The phase diagram of bismuth under static pressure and temperature conditions has been determined to 130 000 kg/cm² and 500°C using the superpressure apparatus developed at the General Electric Research Laboratory. The observations of Bridgman, and others, to 30 000 kg/cm² and 300°C were generally verified. This new work indicates two new solid phases, VII and VIII. The III, VII, liquid triple point occurs at about 22 700 kg/cm², 185°C; the VII, VIII, liquid one at about 43300 kg/cm², 290°C; the V, VII, VIII one at 71 000 kg/cm², 170°C.

A III, IV, VII triple point is suggested at 43 300 kg/cm², 170°C. The VI to VIII transition at room temperature occurs at about 125 000 kg/cm² and involves a sharp decrease in electrical resistance which can serve as a pressure calibration point in future work.

Y6. Effects of Vibrational Spectrum on Transport Properties of Aluminum. A. MEYER, *University of Florida.*—Walker's vibrational spectrum is incorporated into the calculation of transport properties of aluminum. The first required step is to distinguish between terms in the transport integrals which originate from energy and those which originate from momentum. This is done through the use of a modified Kohler-Sondheimer solution, as previously suggested by Ziman. The method for obtaining an averaged-out dispersion relation for aluminum from Walker's vibrational spectrum is shown and then used to convert Bardeen's scattering probability from a function of wave number to a function of frequency. This is, in turn, included in the calculation. The contributions of normal and umklapp processes are modified by the dispersion relation and then included in the calculation. No consideration is made of transverse modes in the normal processes, since aluminum is almost isotropic and the usual assumption is that transverse modes enter the normal processes only in materials anisotropic in their elastic properties. On the other hand, an attempt is made to incorporate the transverse modes in the umklapp processes through the angle between the phonon wave vector and the electron scattering vector $\mathbf{k}'-\mathbf{k}$. The results we have obtained to date and a comparison with the experimental results of Powell are presented.

Y7. Elastic Constants of Silver and Gold. G. A. ALERS AND J. R. NEIGHBOURS, *Ford Motor Company.*—Using the pulsed ultrasonic method the elastic constants of crystalline silver and gold have been determined in the temperature range 298°K to 4.2°K. The extrapolated 0°K values in units of 10^{12} dyne-cm^{-2} are

	C_{11}	$\frac{1}{2}(C_{11}-C_{12})$	C_{44}
Silver	1.315	0.171	0.511
Gold	2.016	0.160	0.454

The room temperature values determined here are in substantial agreement with those of other investigations.[1,2] Using DeLaunay's[3] formula the Debye temperatures are calculated to be $\theta=228$°K for silver and $\theta=162$°K for gold.

[1] R. Bacon and C. S. Smith, Acta Met. **4**, 337 (1956).
[2] E. Goens and J. Weerts, Physik. Z. **37**, 321 (1936).
[3] J. DeLaunay, *Solid State Physics* (Academic Press, Inc., New York, 1956), Vol. 2.

Y8. On the Distribution of Impurity Atoms in the Stress Field of a Dislocation. D. N. BESHERS, *Columbia University.*—Following Louat,[1] we can consider the distribution of impurity atoms near a dislocation and if we consider a single type of impurity, we will arrive at Louat's result. This result is easily rearranged to yield

$$(n_i/N_i)=1/(\alpha e^{U_i/kT}-1),$$

where N_i is the number of sites of energy U_i, n_i is the number of such sites which are occupied by an impurity atom, and α is a parameter of the system. This has the form of the Fermi-Dirac distribution function with $\alpha=\exp(-\epsilon_F/kT)$. We can justify this result independently by considering that the impurity atoms are identical particles of which only one can be placed in any particular site. This result is of great importance in the interpretation of experiments which attempt to measure the binding of impurities to defects by determining the concentration of impurity remaining in solution in equilibrium with the defect as a function of temperature.

[1] N. Louat, Proc. Phys. Soc. (London) **69B**, 459 (1956).

Y9. Electronic Wave Functions in Imperfect Metal Lattices. W. A. HARRISON, *General Electric Research Laboratory.*—A cellular method is proposed for constructing wave functions in distorted monovalent metals and alloys. It involves a straightforward generalization of the cellular method used by Bardeen[1] to calculate the cohesive energies of the alkali metals and is based on the same expansion in wave number. The spherical approximation is replaced by an ellipsoidal approximation due to Hunter and Nabarro.[2] The wave function is written in a generalized Bloch form. The factor which corresponds to the exponential in the periodic case must satisfy a particular differential equation within each cell, as well as specific matching conditions at all cell surfaces. It is found that the resulting wave functions diagonalize the nonperiodic Hamiltonian in the same approximation that the Bardeen solutions diagonalize the periodic Hamiltonian. Hence, if it is assumed that the nonperiodic one-electron potential can be described as spherically symmetric within ellipsoidal cells, the eigenstates can be found in the same approximation as that used in the periodic case.

[1] J. Bardeen, J. Chem. Phys. **6**, 367 (1938).
[2] S. C. Hunter and F. R. N. Nabarro, Proc. Roy. Soc. (London) **A220**, 542 (1953).

Y10. Low-Temperature Heat Capacity of Cu-Ge Alloys. JOHN A. RAYNE, *Westinghouse Research Laboratories* (introduced by T. Holstein).—As an extension of previous work on the α brasses, the low-temperature heat capacity of the primary phase of the copper-germanium system has been measured. When due allowance has been made for lattice expansion, it is found that the change in the electronic heat capacity for low electron/atom ratios is the same for the two systems. In neither case are the changes consistent with the relation derived by Friedel[2] for a parabolic 4*s* band, *viz.*, $\Delta\gamma/\gamma=cZ/3p$, for a solute concentration c of valence Z relative to the solvent, which has p electrons per atom in the valence band. This is taken as providing further evidence that the Fermi surface in copper departs appreciably from spherical shape. The lattice heat capacities will also be analyzed to provide information concerning the variation of elastic constants with solute concentration in each system.

[1] J. A. Rayne, Phys. Rev. **108**, 22 (1957).
[2] J. Friedel, Advances in Phys. **3**, 465 (1957).

Y11. Solution Energy of Dilute Alloys. EDWARD W. HART, *General Electric Research Laboratory.*—The most difficult parts of the problem of computing the solution energy of an impurity atom in a metal is the evaluation of the interaction of the electrons, introduced with the impurity, with the lattice fields and their interaction with the conduction electrons, taking account of correlation and the exclusion principle. It is proposed that these effects can be accounted for if the wave functions of the extra electrons be formed as wave packets constructed from excited one-electron states above the Fermi level. The energy of each such packet is then obtained simply according to the energy of the one-electron states plus the energy of interaction with any fields which were not part of the original lattice. So far as this method has been tried, no change in the conduction electrons has been considered, but instead the solution energy has been computed variationally with a trial wave function. The principal difficulty remaining is the lack of knowledge of the spectrum of the unfilled states. Approximations may be made however. Results will be discussed for H in Cu.

Y12. Theory of Precipitation. FRANK S. HAM, *General Electric Research Laboratory.*—We have calculated the rate of precipitation of solute from supersaturated solution for precipitate particles of various shapes and for different growth conditions. In general, the excess solute density can be approximated as $\rho_{ex}(t)=\rho_{ex}(0)\exp[-(t/\tau)^n]$ during the

first 50% of the precipitation. Under diffusion-limited conditions, n is found to be $\frac{1}{2}$ for spheroids that grow from initially negligible dimensions with constant eccentricity. This result includes disks and rods as well as spheres. We have also found an exact solution of the diffusion equation corresponding to the growth of a spheroidal particle with constant eccentricity under diffusion-limited conditions. Hence a change in eccentricity during growth should ordinarily be attributed to something other than the shape of the diffusion field. Our value of $n=\frac{1}{2}$ for all spheroids does not support Wert and Zener's suggestion[1,2] that n is $\frac{1}{2}$ for disks and 2 for rods under diffusion-limited conditions.

[1] C. Wert, J. Appl. Phys. **20**, 943 (1949).
[2] C. Wert and C. Zener, J. Appl. Phys. **21**, 5 (1950).

SATURDAY AFTERNOON AT 1:45

Grand Ballroom

(J. STEINBERGER presiding)

Cosmic Rays

Z1. Changes in Cosmic Rays from 1954 to 1957.* H. VICTOR NEHER AND HUGH R. ANDERSON, *California Institute of Technology.*—In the period 1954 to 1957 the intensity of cosmic rays changed by a large factor. By cosmic rays we mean the radiation before it comes under the influence either of the earth's atmosphere or of its magnetic field. The ionization at balloon altitudes (i.e., about 15 g cm^{-2} depth) near the north geomagnetic pole in the summer of 1957 was less than half its value in 9954, the area under the ionization-depth curve was down 34%, and the numbers of primary particles was down by a factor of four. Thus, most of the change was in particles of low energy. The intensity of cosmic rays during the present solar maximum is considerably lower than during the solar maximum of 1937. Therefore, the ionization at balloon altitudes in August, 1957, near Thule, Greenland, was 30% lower than in 1937. This is consistent with the higher level of activity of the sun during this cycle compared with that 20 years ago.

* Assisted by the joint program of the Office of Naval Research, the U. S. Atomic Energy Commission, and the International Geophysical Year program of the National Academy of Sciences.

Z2. Cosmic-Ray Increases Associated with Small Solar Flare.* J. J. CORRIGAN, S. F. SINGER, AND M. J. SWETNICK, *University of Maryland.*—Short duration increases in cosmic-ray intensity following a small solar flare were found by a detector designed to follow very rapid intensity changes ($\sim$ a few seconds). The high counting rate telescope is sensitive to low-energy cosmic rays whose effect would be small at low altitudes. The detector was therefore unshielded and flown at 25 000 feet near the auroral zone. A 3-hour flight was made on August 9, 1957. Two 30% increases were observed at 1349 UT and 1433 UT; they lasted for 2 minutes 41 seconds and 1 minute 58 seconds, respectively. A class 1 west limb flare started at 1330 UT. Our observations confirm the expectation that small solar flares produce short increases of low-energy cosmic rays that would have been missed by detectors at low altitudes and latitudes.[1] This may explain why so few solar flares have produced observable increases in the past.

* Supported by U. S. Air Force Office of Scientific Research.
[1] S. F. Singer, IUPAP Cosmic Ray Congress, Varenna, June 1957. Nuovo cimento (to be published).

Z3. Observations on Heavy Primary Cosmic-Ray Nuclei above the Atmosphere.* HERMAN YAGODA, *National Institutes of Health.*—On July 16, 1957, a cylindrical block of *G5* emulsion 8.0 mm in diameter and 10.6 mm thick encased in a thin-walled Dural cassette was exposed to cosmic radiation during the flight of U. S. Air Force Aerobee rocket No. 80 which reached a peak elevation of 123 km. At 46 km the nosecone was ejected thereby exposing the emulsions to the primary radiation for 260 sec with only a total of 137 mg cm^{-2} of local condensed matter present from the vertical. The fragile unit was recovered in excellent condition following a successful parachuting operation. A preliminary survey has revealed the tracks of 26 particles of $Z \geqslant 6$, corresponding to a flux of 5.3 ± 1.1 heavy primaries (m^2·sec·sterad)$^{-1}$ at $\lambda = 41°$N. The M/H ratio is 18/8. In addition 2 boron and 1 beryllium tracks were noted. Collisions were produced in the emulsion by nuclei identified as Be, N, O, and Fe. Two heavy particles interacted with the thin aluminum shell as indicated by the direction of narrow angle beams of secondary tracks. In one of these external events a jet composed of a lithium nucleus, 2 alpha particles, and 37 singly charged relativistic particles entered the top emulsion layer indicating the interaction of a particle of $Z \geqslant 7$ at a depth of 85 ± 15 microns below the polished aluminum surface. The angular divergence of the multiply charged secondaries provides an estimate of 34 Bev per nucleon for the incident particle.

* Exposure secured in conjunction with the U. S. Air Force Cambridge Research Center micro-meteorite program.

Z4. On the Origin of Cosmic Rays. JOSEPH G. BARREDO, *C.S.I.C.** (introduced by R. J. Moon).—Since quantum electrodynamics, relativity, and even Coulomb's law do not hold for distances $\leqslant 10^{-13}$ cm or times $\leqslant 10^{-23}$ sec, the opinion is growing that concepts like timeless jumps, waves, linearity fields, external coordinates, interactionless mass, and structureless particles are meaningless. Since one never observes a particle but only the interaction of particles, the nonlinear equation I (current) $= KN^{n}t^{-1}$(1) was deduced, avoiding the foregoing concepts. As shown, Eq. (1) (a) can be written as a function of distances in the particle, without external coordinates; (b) reduces to Coulomb's law (fixed time, t) or Ohm's law ($t \to \infty$); (c) predicts a proved phenomenon called chronosuperconductivity, showing the configuration of any particle to be a trion, i.e., a carrier in front of a dipole spinning around the configuration center; (d) allows measuring its dimensions through its binding energy. The trion concept indicates that cosmic-ray energy could be produced by fusion of a trion (the cosmon) with a binding energy $\geqslant 10^{15}$ ev to which the corresponding length is $\leqslant 10^{-28}$ cm [see calculations of deuteron's dimensions, confirmed by Rochester High Energy Conference conclusions (to be published)] and explains why a point charge electron gives infinite self-energy and why a nonpoint charge is not invariant under Lorenz's transformation. This transformation fails to define any particle because of the unstability of charges and mass within the particle due to interactions.

* Now at the University of Chicago.

Post-Deadline Papers, If Any

SUPPLEMENTARY PROGRAMME

SP1. Integer-Valued Constants of Motion in General Relativity. DAVID FINKELSTEIN, *Stevens Institute of Technology and New York University.**—As has been pointed out by Anderson and Mizner, the constants of motion of general relativity are just the quantities constructed from the gravitational field that are invariant in form and value under arbitrary coordinate transformations. *A fortiori*, invariants under arbitrary continuous deformations of the gravitational field are also constants of the motion. As an illustration, a quantity n which is a functional of the gravitational field taking the values $0, \pm 1, \pm 2, \ldots$ is exhibited which has some of the properties of a particle number. Its value is zero for a universe which is deformable to flat Minkowski space. In a typical universe where $n = \pm 1$, there is a small region where the flow of time is backwards. In general, n counts the number of such regions, with negative values arising from the possibility of a sort of pair annihilation. (The values of n are obtained as the elements of the third homotopy group of the space of symmetric tensors of signature $+\cdots$.)

* To be given at the end of Session XA if the Chairman rules that time permits.

SP2. New Conception of the K Meson.* CHARLES J. GOEBEL, *University of Rochester.*—At the Rochester Conference, 1957, M. Gell-Mann presented a scheme for implementing the idea that the pion was coupled equally to all baryons. To get around the difficulty that the isotopic spin i of all the baryons is not the same, he represented each baryon as an eigenstate of the a spin and b spin, let me call them. (For N and Ξ $\mathbf{i} = \mathbf{a}$; for Σ and Λ $\mathbf{i} = \mathbf{a} + \mathbf{b}$.) The pion is taken to be an a spin vector. Now, consider a boson χ which is a b-spin vector and which couples $(N\Xi)$ to $(\Sigma\Lambda)$. If we adjoin a b-spin scalar q which has odd charge (and time) parity, we find that (χq) is equivalent to $(K^+\theta_1 K^-, \theta_2)$; i.e., the usual strangeness is conserved. Note that the absence of an isotopic scalar "pion" does not mar the symmetry, for the coupling of such a "pion" having odd charge parity vanishes identically.

* To be given after paper GA4 if the Chairman rules that time permits.

SP3. Relativistic Quantum Mechanics with a Momentum Cutoff.* T. A. WELTON, *Oak Ridge National Laboratory.*—A number of phenomena point with some force to the necessity of introducing a cutoff momentum into relativistic quantum mechanics. Unfortunately, such attempts within the framework of conventional theory always have a rather arbitrary appearance. A new formulation has been devised in which field quantization is unnecessary either for consistency or to obtain the results of conventional calculation. In this new theory, simple commutation relations between coordinate operators can be introduced, which effectively impose a smallest length, without any assumption of an arbitrary form factor. New expressions for interparticle forces and self-energies have been obtained in the photoelectron and pion-nucleon cases. A crucial experiment would be the electron-electron scattering at high relative energy and cross-section predictions for this case will be given.

* To be given at the end of Session MA if the Chairman rules that time permits.

SP4. Skewness and Flatness Factors of the Distribution of $\partial^n u_1/\partial x_1^n$ at Hugh Reynolds Numbers.*† ROBERT H. KRAICHNAN, *New York University.*—The universal range spectrum form and autocorrelation function for huge Reynolds number R given in an accompanying abstract[1] are found to yield for the skewness factor of the distribution of $\partial^n u_1/\partial x_1^n$ the value $S_n \approx A_n R^{-1/6}$, where A_n is a universal constant. Although measurements at high enough R to provide a conclusive discrimination are not available, this R dependence is more compatible with examined data[2] than the asymptotically R-independent behavior required by the Kolmogorov similarity hypothesis. The present theory yields expressions for fourth-order, velocity-derivative moments in terms of the functions $E(k)$ and $r(k,\tau)$. From these it is found that the flatness factor of the distribution of $\partial^n u_1/\partial x_1^n$ approaches, for each n, a universal finite limit as $R \to \infty$. The theory also yields finite universal limits for quantities of the type $\langle(\partial u_1/\partial x_1)^2\rangle\langle(\partial^3 u_1/\partial x_1^3)^2\rangle/\langle(\partial^2 u_1/\partial x_1^2)^2\rangle^3$. Both of these results are compatible with examined data.[2]

* Supported by the Geophysics Research Directorate, Air Force Cambridge Research Center.

† To be given at the end of Session X if the Chairman rules that time permits.

[1] R. H. Kraichnan, Bull. Am. Phys. Soc. Ser. II, 3, 65 (1958).
[2] G. K. Batchelor, *The Theory of Homogeneous Turbulence* (University Press, Cambridge, 1953), pp. 118–119, 172–175.

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Rosen, J.—F7
Rosenstock, Herbert B.—V8
Roth, L.—E8
Rothman, M. A.—F5, N10
Rothstein, Jerome—P11
Rubin, Allen G.—U9, U11
Rubin, Robert J.—MA1
Ruby, S. L.—KA10
Rudinger, George—X6
Russell, James E.—VA3

Sachs, A. M.—M9, SA12
Sachs, Rainer—XA3, XA4
Sailor, V. L.—EA6
Sakurai, J. J.—C3
Samios, N.—HA8
Sapp, R. C.—PA2
Sard, R. D.—M11
Sato, H.—PA5
Sayers, J.—NA2
Scarf, F. L.—V7
Schaeffer, O. A.—U12
Scharenberg, R. P.—U1
Schiffer, J. P.—N7
Schiller, Ralph—MA9
Schlier, R. E.—KA2, R8
Schlömann, E.—PA11
Schmidt, Bernhard M.—H10
Schmitt, H. W.—N6
Schupp, F. D.—KA10
Schwartz, M.—HA8
Schweber, S. S.—C5
Scott, T. A.—H11
Segel, Ralph E.—W7
Seidel, G.—EA4
Sellen, J. M.—M4
Serbin, Hyman—X11
Sessler, A. M.—T10
Seth, K. K.—F9
Shafroth, S. M.—N5
Sherman, I.—UA10
Sherwood, R. D.—PA9
Shore, F. J.—EA6, F11
Shulman, R. G.—PA1
Silver, A. H.—H4
Silverman, A.—HA3
Simms, F. C.—SA9
Simon, Albert—P8
Simpson, J. Arol—R11, R12
Simpson, J. H.—H8
Singer, S. F.—P7, Z2
Sladek, R. J.—E10
Smith, Arthur C.—D9
Smith, E. A.—H7
Smith, G. M.—Y2
Smith, J. R.—A5
Smith, T. S.—H7
Smith, W. G.—VA2
Smotrich, H.—J7
Smyth, H. D.—L1
Snell, Arthur H.—P4, VA11
Snow, George A.—C7
Solmitz, F. T.—HA9, HA10
Sood, P. C.—S3
Stadler, Henry L.—Q1
Stahelin, P.—SA13
Statz, H.—D5, D6
Steffen, R. M.—SA9
Stehney, A. F.—A4
Stein, P. C.—M2
Steinberger, J.—HA8, MI3
Stelson, P. H.—DA1
Stemple, N.—V2
Stevenson, James R.—R4, R5
Stevenson, M. L.—HA9, HA10
Stout, J. W.—PA1
Strait, E. N.—N5
Strandberg, M. W. P.—B11
Stupp, E.—B10
Sturkey, Lorenzo—G2
Sucher, J.—S7
Sudarshan, E. C. G.—GA1
Sullivan, R. P.—W2
Summers, R.—M10
Swann, C. P.—J5
Swetnick, M. J.—Z2

Taft, E.—R7
Tamor, Stephen—T6, T7
Tautfest, G. W.—J1
Terman, F. W.—H11
Thaddeus, P.—K1
Theimer, O.—V9
Thorndike, A. M.—M6
Thouless, D. J.—GA3
Ticho, H. K.—HA9, HA10
Tinlot, J.—HA7, M5
Tokunaga, K.—XA10
Toll, J. S.—MA11
Toms, M. Elaine—U4
Townes, C. H.—B12
Traub, J.—T2
Trees, R. E.—K7
Trigger, K. R.—B9
Tuck, James—JA1
Turkevich, Anthony—U13
Tycko, D. H.—SA12
Tyler, W. W.—E5

Uretsky, Jack L.—C13

Vaglio-Laurin, R.—X9
Van Patter, D. M.—F5, N10
Vedam, K.—Q3, Q4, Q5
Vook, Richard Werner—KA13

Wacker, P. F.—K3
Wada, W. W.—S2
Wallis, Richard F.—T1
Wangsness, Roald K.—PA13
Waniek, R. W.—UA4
Watson, K. M.—S13
Weinrich, M.—SA8
Weinreich, O.—D12
Welton, T. A.—UA2, UA3, SP3
Weneser, J.—W10
Wenzel, W. A.—TA4
Wertheim, G. K.—KA11
Westerberg, E.—UA10
Whetten, N. R.—R6
White, J. A.—B1, B2
White, R. S.—HA1, HA12
Whitehead, M. N.—HA4, HA5
Whittemore, William L.—K2
Wilkinson, M. K.—G4
Willard, H. B.—F2
Williams, Dudley—H10
Williams, H. J.—PA9
Williams, John H.—SA4
Willis, W. J.—M6
Wilson, R.—HA3
Wilson, R. R.—M1
Wilson, Richard—DA4
Wolley, E. D.—KA10
Wolsky, Sumner P.—D4
Wood, G. T.—W11, W12
Woodruff, T. O.—V12
Woodward, W. M.—M1
Woods, R. M., Jr.—W4

Yahia, J.—EA3
Yakimac, Alexis—P13
Yagoda, Herman—Z3
Yamazaki, K.—V11
Yearian, M. R.—SA1
Yen, J. T.—X8
Yevick, G. J.—MA12, T12
Yntema, J. L.—U8
Young, Donald E.—SA3
Yule, H. P.—U13

Zähringer, J.—U12
Zaidi, M.—C8
Zeidman, B.—U8
Zemach, C.—S13, XA9
Zimmerman, R. L.—F8, F9, F10
Zimmerman, S.—P1
Zipoy, D.—M1
Zorn, B. Sechi—HA6
Zorn, G. T.—HA6
Zucker, A.—N8, N9
Zwerdling, S.—E8

HOTEL INFORMATION

The New Yorker is the headquarters hotel. Reservations should be sent directly to Mr. Thomas Hurd, Front Office Manager of the New Yorker, in the manner directed below. Please tear off the attached and use as your room reservation blank. Be sure to specify the persons for whom reservations are being made. All rates quoted are for the room, and in the event of more than one person occupying the room the rate can be shared. If a third person is housed in the room, the cost of the extra "roll-away" bed will be added to the cost of the room.

If a room at the rate requested is not available, one at the nearest available rate will be reserved for you. Be sure to bring the confirmation slip with you as proof of your reservation. In fairness to others, please make a cancellation if your plans change. Unless otherwise requested, the hotel will hold reservations only to 6 P.M. of the day of your arrival. Check out time is 3 P.M.

HOTEL RATES

HOTEL	Room and Bath for one per day	Double-Bed Room with Bath for two per day	Twin-Bed Room with Bath for two per day	One Room for 3 persons with Bath per day	Suites Living Room Bedroom and Bath for one or two per day
New Yorker 34th Street at 8th Avenue	$8–$13	$11.50–$16.50	$14.50–$19.50	$15–$18	$25.00 and up

NOTE: All rates subject to New York City 5% hotel room tax.

Tear Off Tear Off

To: FRONT OFFICE MANAGER
HOTEL NEW YORKER
34TH STREET AND 8TH AVENUE
NEW YORK, NEW YORK

A.P.S.

Please enter my reservation for a single / double / twin bedroom at approx. $..... to $..... per day for the 1958 A.P.S. Meeting. I / We plan to arrive ..... and remain until .....

Print below persons in your party.

.....
Signature

.....
Address (Street or P.O.)

.....
Town or City and State

Second Announcement of the 1958 March Meeting

The 1958 March meeting of the American Physical Society will be held in Chicago, at the University of Chicago and under the auspices of the Institute for the Study of Metals thereof, on Thursday, Friday, and Saturday, March 27, 28, and 29. This is the meeting at which our Divisions of Solid-State Physics and High-Polymer Physics present their largest and most numerous programmes of the year. The official hotel is the Windermere, at 1642 East 56th Street, Chicago 37. After its own accommodations are fully booked, the Windermere will place our members in other hotels of that region (which, for those not yet acquainted with Chicago, may be described as the most convenient of all to the University). In writing to the Windermere, mention that you are a member of the Society coming for this meeting. **Deadline for abstracts** of contributed papers is Friday, January 17.

There will be no Southwestern meeting this year, but it is intended to resume the Southwestern sequence in late February or in March of 1959.

Announcement of the 1958 Washington Meeting

The 1958 Spring meeting of the American Physical Society will be held in Washington, D. C., at the Sheraton-Park and the Shoreham Hotels and the National Bureau of Standards, on Thursday, Friday, and Saturday, May 1, 2, and 3. These are the latest days of the year on which our Spring meeting ever falls, or ever will so long as the National Academy of Sciences maintains its present schedule and we maintain our own tradition of beginning our meeting just after its meeting ends. Room reservations are to be made by writing to the Sheraton-Park Hotel, Washington 8, D. C., and specifying that the writer is a member of this Society coming to this meeting. The Sheraton-Park engages to provide rooms in other hotels after its allotment to our members is fully booked: our members may designate the hotels of their choice. It is a good idea to see to this matter before the Washington Bulletin appears. **Deadline for abstracts** of contributed papers is Friday, February 21.

MEETINGS AND DEADLINES FOR 1958

Place	*Meeting dates*	*Deadline date*
Stanford, California	December 19–21	past
New York	January 29–February 1, 1958	past
Chicago	March 27–29	January 17
Washington	May 1–3	February 21
Ithaca, New York	June 19–21	April 18
Vancouver, *British Columbia	August 26–28	June 27
not decided	November 28–29	September 26
Los Angeles	December 18–20	October 17

* Abstracts for the Vancouver and Los Angeles meetings are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline-day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 P.M. Allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west. To avoid chance of confusion, please do not send an abstract for any meeting until the deadline date of the previous meeting is at least five days past. *The privilege of contributing papers to meetings of the American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

RULES AND INSTRUCTIONS FOR THE PREPARATION OF ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten; one must be an original, the other may be an original or a carbon copy. *They must be double-spaced:* single-spaced manuscripts are too crowded to permit the editorial markings to be made with ease and clearness. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. *If we receive an abstract typed on two pages, we print only its first page.* Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Do not use very thin paper; a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged, and follow the example. Issues of the *Bulletin* are always appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

It now becomes an expensive business to make any change in an abstract, even the smallest, after the abstract has gone to press. By order of our Council "A change in an abstract will be permitted only at the discretion of the Secretary or his deputy, and only if TEN DOLLARS is enclosed with the letter in which the change is requested." As heretofore, an abstract will not be withdrawn from proof unless the asker sends ten dollars with his request.

Important Notice to Members and Fellows of the American Physical Society

A new Membership List of the American Physical Society will be issued in 1958, and it is highly desirable that this be as nearly complete and accurate as possible. Shortly after January 1, 1958, you should receive by first-class mail, in a window envelope, a return-addressed postal card bearing your name and address of present record, together with instructions for its immediate return emended as necessary. If you do not receive this postal card before January 31, 1958, notify the undersigned of your name and address as you wish them to appear in the Membership List. If your professional affiliation does not appear in your address, this additional information is requested.

SHIRLEY L. QUIMBY
Pupin Physics Laboratories
Columbia University
New York 27, New York

Proceedings of the American Physical Society

Minutes of the Tenth Annual Gaseous Electronics Conference Held at Cambridge, Massachusetts, October 2, 3, and 4, 1957

THE Tenth Annual Gaseous Electronics Conference was held at the Massachusetts Institute of Technology at Cambridge, Massachusetts, on October 2, 3, and 4. The Conference was jointly sponsored by the Division of Electron Physics, the Sylvania Electric Products, Inc., and the Massachusetts Institute of Technology. The title of the invited paper and the abstracts of the 41 contributed papers are printed below. There were 297 registrants.

The Conference banquet was held on Friday evening, October 4. Giorgio de Santillana of the Massachusetts Institute of Technology was the after-dinner speaker. He presented a talk on the "Trials of Galileo."

The Conference Committee for the coming year consists of W. P. Allis (Chairman), Sanforn C. Brown, L. H. Fisher, J. A. Phillips, and D. J. Rose (Secretary).

S. C. Brown, *Secretary*
1957 Gaseous Electronics Conference

Positive Column

A1. Low-Temperature High-Density Plasmas. R. C. Knechtli and W. Knauer, *Radio Corporation of America.*—A method for producing a "cool" or monochromatic electron beam is described. It is based on the reduction of the thermal energy of thermionically emitted electrons by thermalizing collisions of these electrons with the molecules of a cool gas. Such a low-temperature electron beam could be used for ultra-low-noise traveling-wave tubes or for basic physical research. Because the electrons can drift only very slowly through the cooling gas (otherwise they would heat up instead of being cooled!), their density must be very large. The resulting space charge is neutralized by means of cesium ions produced by contact ionization. Electrons and ions are confined in a plasma beam by means of a magnetic field of a few hundred gauss. After having drifted through the cooling gas, this plasma beam extends through a differential pumping system and emerges in high vacuum. There, the electrons are extracted from the cool plasma, and a monochromatic electron beam of controllable energy is formed. An analysis was made of the properties of the magnetically confined dense plasma beam. Probe measurements were found to be compatible with the theory. Interesting recombination effects have been discovered.

A2. Temperature Measurements in High Current Arc Plasmas. H. N. Olsen, *Linde Company.*—Temperatures in the range 10 000 to 22 000°K have been measured spectroscopically in thermal plasmas of high current argon arcs. The method used was developed originally by Fowler and Milne[1] and later adapted for measurements in transparent plasmas by Larenz.[2] Spectrally resolved radiation intensity maps, corrected for variation of depth of radiation with position in the plasma, were obtained on a relative intensity scale for arcs burning in both the normal mode and the cathode-spot mode. Isotherm maps covering the foregoing temperature range were constructed from the spectral maps. Plasmas studied were those of nonconsumable electrode arcs provided with sufficient electrode cooling to prevent metal vapor contamination. The arcs, operating in an enclosed chamber to avoid atmospheric contamination, burned between a tungsten-rod cathode and a plane copper anode. Chamber gas was argon at atmospheric pressure. Currents ranged from 100 to 400 amperes.

[1] R. H. Fowler and E. A. Milne. See A. Unsold, *Physik der Sternatmosphären* (Berlin, 1938).
[2] R. W. Larenz, Z. Physik 129, 327–342 (1951).

A3. Dynamic Response of Arcs in Various Gases. T. E. Browne, Jr., K. H. Yoon, and H. E. Spindle, *Westinghouse Electric Corporation, Trafford.*—The dynamic volt-ampere behavior of an arc column can be described by means of differential equations in which energy storage in and power loss from the column account for time lag effects. The ratio of an energy quantity to power loss appears as a "time constant." This constant and the steady-state voltage gradient are sufficient as parameters in simple arc "model" equations. Such equations can be solved simultaneously with those of the supply circuit to determine, for example, arc stability limits. A method for measuring arc time constants for use in a modified Mayr-type equation will be described. Results will be given showing close correspondence between computed behavior and observed behavior of low current vertical semi-confined arcs in still gas. Arc currents from 1 to 6 amperes and gas pressures from ½ to 7 atmospheres have been used. Time constants have been found to increase with enclosure diameter, gas pressure, and arc current, and to be extremely dependent upon gas medium. Values range from ½ microsecond in sulfur hexafluoride at low pressure to hundreds of microseconds in nitrogen at higher pressures. Physical explanations for these variations are being sought.

A4. Deviations from Ionization Balance—A Tool for Studying Ionization Processes in a Plasma. John F. Waymouth, *Sylvania Electric Products,* and Francis Bitter,* *MIT.*—An experiment has been devised for switching an operating discharge to a zero-impedance power supply whose voltage can be varied above or below the equilibrium discharge voltage just prior to switching. If the zero-impedance voltage is above the discharge voltage, the electron density and discharge current increase with time, tending toward infinity. If the zero impedance voltage is below the equilibrium discharge voltage, the electron density and discharge current decrease with time, tending toward zero. The discharge is switched back to its ballasted power supply before catastrophic damage or extinction occur. From the rate of change of electron density with time, information can be obtained about the ionization processes in the discharge.

* Work done at Engineering Laboratories of Sylvania Electric Products, Salem.

A5. Transition from Non-Maxwellian to Maxwellian Electron Energy Distributions in Rare Gas Discharges. G. Medicus, *Wright-Patterson Air Force Base.*—In hot-cathode

rare gas discharges in the mm pressure range, high-energy (8–16 ev) electron groups, superimposed on a Maxwellian, are usually observed. In a Ne fire-ball discharge, families of electron energy spectra were determined from automatically plotted probe curves by a short cut[1] to Druyvesteyn's method, with the probe location and the discharge current as parameters. At low currents the high-energy group is clearly separable and is found to obey simple diffusion laws, with no interaction within itself, but with energy transfer to the Maxwellian group. The temperature of the latter group initially rises in proportion to the total current. With increasing total current and rising temperature the energy transfer increases, and the fast group progressively disappears into the Maxwellian, until at total currents in the ampere range, at electron temperatures of about 20 000°K, the deviations from the Maxwellian practically disappear except for a persistent deficiency in the high-energy Maxwellian tail.

[1] G. Medicus, J. Appl. Phys. **27**, 1242 (1956).

A6. Theory of Moving Striations. P. J. WALSH, *Westinghouse Electric Corporation*.—The coupled continuity equations for the electrons and ions in a plasma have been treated by Watanabe and Oleson.[1] Unfortunately, the simultaneous diffusion of electrons and ions to the tube walls was handled incorrectly by them. When this diffusion is treated correctly it is found that the striation wavelength and velocity are determined solely by nonlinearity in the ionization rate and by any change in the electron parameters produced by the energy variation within the striations. This energy variation is determined by the use of the power balance equation for the electrons. Preliminary calculations show good agreement with experiments conducted in mercury-krypton discharges.[2]

[1] S. Watanabe and N. L. Oleson, Phys. Rev. **99**, 1701 (1955).
[2] H. L. Steele, Gaseous Electronics Conference, paper F3, (1950).

A7. Studies of Cataphoresis in Discharges in Mixtures of Gases; Two New Effects. C. KENTY, *General Electric Company, Nela Park*.—Measurements have been made of the transport of Hg along the positive column of a dc discharge in mixtures of Hg with the rare gases. The unexpected retrograde transport of Hg in Xe is due to a drift of neutral Hg toward the anode under the impact of the electrons which exceeds the drift of Hg ions toward the cathode. This is made possible by the relatively large Ramsauer cross section of Hg and the inferred presence of numerous Xe ions. An ac discharge in Ne plus a trace of A concentrates the A axially toward the middle of the column. Similarly, Hg is concentrated toward the middle of a column in Ne+Hg, A+Hg or Kr+Hg but toward the ends in Xe+Hg. The effect increases with current and rare gas pressure and decreases with increasing Hg pressure. It is probably caused by nonuniformity of field due to traveling striations or other asymmetric effect.

Cathodes

B1. Hollow Cathode Glow Discharge in Mercury Vapor.* K. G. HERNQVIST, *RCA Laboratories*.—The hollow cathode glow discharge operates with a metal cathode having a a spherical cavity and a small exit aperture. The main glow is situated inside the cathode cavity. This discharge has been operated in mercury vapor by keeping the inside of the cavity wetted with mercury. The volt-ampere characteristic does not exhibit any regions of negative resistance. An analysis based on the energy balance relation will be shown to yield a volt-ampere characteristic which is in good agreement with experiment. Microwave measurements of the plasma density also corroborate the analysis. These studies indicate that plasma densities in excess of 10^{15} cm^{-3} may be obtained in this discharge.

* This research was supported by the United States Army Signal Corps.

B2. Cathode Sheath in a Low Density Discharge. P. L. AUER, H. HURWITZ, JR., AND S. TAMOR, *General Electric Research Laboratory*.—We consider a gaseous discharge between two plane parallel electrodes under the assumption that the electron current at the cathode is space charge limited. We shall be particularly interested in studying the variation of the potential distribution with gas pressure. When the gas pressure is very low, little ionization is produced so that the potential distribution follows the Langmuir-Child's law. As the gas pressure is increased, the positive ion space charge reverses the curvature of the potential near the anode and eventually leads to the formation of a positive column. The present work is an extension of the classical paper published by Langmuir in 1929.[1] We shall exhibit self-consistent solutions for the cathode sheath potential distribution on the basis of a model in which the space charge results from the primary electrons and from ions generated within the cathode sheath region. Also considered is the case in which the anode (which may be regarded as the boundary of the positive column next to the cathode sheath) emits additional ions contributing to the space charge.

[1] Irving Langmuir, Phys. Rev. **33**, 954–989 (1929).

B3. Motion and Spectrum of High-Speed Cathode Spots. DINO ZEI AND J. G. WINANS, *University of Wisconsin*.—The motion and spectrum of a mercury arc cathode spot was observed at a junction between metal and mercury and at a groove above the liquid-metal junction. For all magnetic field strengths the spot velocity at the groove was greater than at the junction. For constant field, the spot velocity at the groove showed a maximum at about two amperes with increase in current. The spot velocity at the junction increased with current for all currents. The spot at the groove was about 5 mm long and 1 mm wide. The spectrum of the spot at the groove showed Hg 1, Hg 11, and Hg 111 lines. There is no broadening of the spectrum lines at the spot as observed for a spot at the junction. The mechanism proposed by St. John and Winans[1] accounts for both groove and junction modes of operation of the arc.

[1] R. St. John and J. G. Winans, Phys. Rev. **94**, 1097 (1954).

B4. Mechanism of Electron Emission in Arcs on Low Boiling Point Cathodes. T. H. LEE, *General Electric Company, Philadelphia*.—There has been considerable difficulty in explaining the mechanism of electron emission in arcs on low boiling point cathodes such as copper or silver. Cobine and Burger[1] have shown that thermionic emission is unlikely and the electric field at the cathode calculated from the MacKeown equation[2] is too low to account for the electron emission by the Fowler-Nordheim mechanism of field emission. Thermionic emission (including the Schottky effect) and field emission are really the limiting cases of a more general emission equation treated by Murphy and Good.[3] In the intermediate range, where both field and temperature are high the emission process is strongly dependent on both variables. Dolan and Dyke[4] have proposed the term "*T-F*" emission for this region. In this paper, the "*T-F*" emission is calculated over a wide range of temperature and field. It is then shown that the electron emission in arcs on low boiling point cathodes may be explained by the mechanism of "*T-F*" emission.

[1] J. D. Cobine and E. E. Burger, J. Appl. Phys. **26**, 895 (1955).
[2] S. S. MacKeown, Phys. Rev. **34**, 611 (1929).
[3] E. L. Murphy and R. H. Good, Jr., Phys. Rev. **102**, 1464 (1956).
[4] W. W. Dolan and W. P. Dyke, Phys. Rev. **95**, 327 (1954).

B5. Transport with Dissipation. DON E. HARRISON, JR., *University of Toledo.*—This paper describes a technique which will solve the Boltzmann transport equation for a special case in which kinetic energy is not conserved in an individual collision. It consists of a neutron cooling type analysis combined with a suitably modified energy, or "lethargy," transition function. Conservation of momentum is maintained by a transformation to the center-of-mass system, but kinetic energy is removed by fractionally reducing the final velocity of both the striking and struck particles. The fraction retained introduces a new *dissipation parameter* into the theory. The usual transition probability analysis can then be carried through, and all functions retain the same general characteristics although they now depend upon both the mass ratio and the dissipation parameter. The new method will be applied to the author's theory of cathode sputtering,[1] and certain other analytic techniques which simplify that analysis will also be discussed. As modified, the theory compares satisfactorily with a much broader range of experimental data. This new method is particularly useful because it makes no restrictions on the way in which energy is being removed from the kinetic system. In the case to be discussed, this energy is available to rupture lattice bonds, but it could equally well be utilized for electron excitation or radiation.

[1] Don E. Harrison, Jr., Phys. Rev. **102**, 1473 (1956) and Phys. Rev. **105**, 1202 (1957).

B6. Details of Behavior of a Wire during Electrical Explosion. WILLIAM G. CHACE, *Air Force Cambridge Research Center.*—Wires subjected to very high current densities ($>10^8$ amp/cm^2) become highly superheated and vaporize "instantaneously." The term "transplosion" is proposed for this process. The conductivity changes from metallic to gaseous type with a decrease in magnitude of 10^2 to 10^4 times. How these changes effect the current behavior depends on composition and dimensions of the wire and on capacitor voltage. Oscillograms record five types of behavior, but it will be shown that all are really variations of the *D* type. This is the type with the well known exploding wire "dwell" or "dark" time. It is proposed that this is not a time of zero current, but one of low current. Based on oscillograms and fractional microsecond photographs, a hypothesis is advanced that dwell is the result of a high ratio of field strength to pressure which prevents avalanching and restricts current flow to scarce carriers. Reignition is, then, breakdown made possible by decreasing pressure. An equation based on this theory predicts dwell times with satisfactory accuracy as composition and dimensions of wire are changed.

B7. Arc Initiated Discharge in Magnetic Field in High Vacuum. II. Magneto-Ionic Expander Type of Discharge. JOSEPH SLEPIAN, *Westinghouse Research Laboratories.*—A short arc between electrodes in a parallel magnetic field set in the middle of a relatively not so short, high vacuum tank giving a current to the tank wall positive or negative, not limited by space charge, was described here last year. This ionic centrifuge took a high voltage but was ineffective for isotope separation. The same arc placed between two expander electrodes between which a high enough difference of electrical potential is applied feeds ions and an equal amount of electrons to a set of insulated slats which terminate the expander tube, and thus forms a discharge of quite different properties. The expander electrodes are placed initially at less than an inch respectively from the arc, but they expand so they embrace a distance of two or more feet at the insulated slats. A net current is induced which is entirely closed within the gas itself; termination upon the expander electrodes is prevented by the action of the magnetic field. The action of this induced net current upon the ions and electrons which pass through it en route to the insulated slats causes the random velocity to approach zero, and the mean velocity of approach to the individual slats to be common to the isotopes. The isotopes of the ions become separated. The enrichment giving light ions on the slats near the negative expander and heavy ions on the slats near the positive expander is great enough so that essentially pure isotopes are obtained in one stage. An arc of 100 amperes will give approximately a cost per gram of U^{235} of $8.00; a 1000 ampere arc, less than $2.00. The cost of the presently used diffusion method is more than $15.00 per gram of U^{235}.

Cross Sections

Contributed Papers

C1. Further Studies of the Imprisonment of Resonance Radiation. A. V. PHELPS AND A. O. MCCOUBREY,* *Westinghouse Research Laboratories.*—The relative importance of the diffusion of resonance atoms and the escape of resonance radiation for mercury 6^3P_1 resonance atoms has been determined from studies of decay of the 2537 A resonance radiation following a period of optical excitation.[1] Holstein's theory of the imprisonment of resonance radiation[2] predicts decay constants at fixed temperature which are a function only of the product of the mercury density and the radius of the cell. Diffusion theory predicts decay constants which are inversely proportional to the product of the mercury density and the square of the radius.[3] Using a combined theory, the results show that diffusion is negligible and that the predictions of imprisonment theory are confirmed to within 15%. The experiment sets an upper limit to the production of the diffusion coefficient and the gas density of 5×10^{17} atoms/cm-sec at 340°K, which is consistent with a value of 4×10^{18} atoms/cm-sec from theory.[4]

* Now at The National Company, Incorporated, Melrose, Massachusetts.
[1] Alpert, McCoubrey, and Holstein, Phys. Rev. **76**, 1257 (1949).
[2] T. Holstein, Phys. Rev. **72**, 1212 (1947); Phys. Rev. **83**, 1159 (1951).
[3] R. G. Fowler, *Handbuch der Physik* (Springer-Verlag, Berlin, 1956), Vol. 22, p. 226.
[4] Holstein, Alpert, and McCoubrey, Phys. Rev. **85**, 985 (1952). As in the case of charge transfer collisions, the diffusion coefficient was calculated by assuming the cross section for momentum transfer to be twice the cross section for excitation transfer.

C2. Excitation Functions and Rates for the Principal Levels of Helium. L. S. FROST AND A. V. PHELPS, *Westinghouse Research Laboratories.*—Cross sections and rates of excitation by electrons have been evaluated for the 2^1S and 2^3S metastable and the 2^1P resonance levels of the helim atom. The cross section for excitation to each He level up to a principal quantum number n equal to 6 was arrived at using the available optical and electrical measurements and theoretical results.[1] Cascading was computed to obtain the total excitation cross section to the principal $n=2$ levels; effects of collisional transfer of excitation and of imprisonment of resonance radiation were included in the analysis. The rates of excitation obtained by integrating the total cross sections over published electron energy distribution functions[2] are in essential agreement with the microwave measurement of total metastable production by MacDonald and Brown.[3]

[1] H. S. W. Massey and E. H. S. Burhop, *Electronic and Ionic Impact Phenomena* (Oxford University Press, London, 1952), Chaps. II and III.
[2] I. A. Smit, Physica **3**, 543 (1936); F. H. Reder and S. C. Brown, Phys. Rev. **95**, 885 (1954).
[3] A. D. MacDonald and S. C. Brown, Phys. Rev. **75**, 411 (1949).

C3. Total Ionization by Low-Energy Electrons in Neon. B. T. MCCLURE, *Bell Telephone Laboratories.*—The average number of ions, n, which are created by low-energy electrons when they are stopped in a field free region is an important

parameter in connection with certain gas discharge problems. Johnson[1] measured n in a number of gases and found general agreement with the values obtained by stopping highly energetic α and β rays. In extending Johnson's work, we inject electrons having well defined energies up to 200 volts into neon. When the primary electrons are neither reflected to their source nor collected by the container before being cooled below the ionization potential, the total number of ions which they produce is a good measure of n. When the primary electron energy is less than the sum of the ionization and minimum excitation energies (38 volts for neon), n determines the ratio of the total excitation probability to the ionization probability. Preliminary data indicate that the total excitation probability increases rapidly with energy up to a peak and thereafter decreases in the manner generally expected for excitation. The magnitude and energy dependence of n for neon are of the same order as reported by Johnson.

[1] J. B. Johnson, Phys. Rev. **10**, 609–623 (1917).

C4. Mobilities of Ions in Rare Gases at Low E/p_0. EARL C. BEATY, *National Bureau of Standards.*—An apparatus to measure the mobilities of ions in gases with greater accuracy and resolution, and at lower values of E/P_0 than has been previously possible, has been developed to a point where useful data is being obtained. A double shutter method is used with fast square pulses driving the shutters. Detection of the ions is currently being done by an amplifier-oscilloscope combination, and the time of flight of the ions is measured using the calibrated oscilloscope sweeps. The second shutter is not now used but eventually will serve to isolate the detection equipment from the timing equipment permitting greater sensitivity and resolution. Data in the rare gases have been obtained at values of E/p_0 less than 1.0 volts/cm-mm Hg, in argon, making the extrapolation to zero E/p_0 much more reliable. The lowest value of E/p_0 for which measurements have been made previously is about 8 volts/cm-mm Hg. Preliminary results will be presented and compared with those of other investigators.

Invited Paper

C5. Rocket Investigation of Atmospheric Photochemistry. FREDERICK F. MARMO, *Air Force Cambridge Research Center.*

Contributed Papers

C6. Electron Attachment in Oxygen at Low Energies. LORNE M. CHANIN AND MANFRED A. BIONDI, *Westinghouse Research Laboratories.*—Measurements have been made of the electron attachment cross section in oxygen using a double shutter drift tube of the type developed by Pack and Phelps.[1] This tube permits attachment studies at lower electron energies than have been reached previously (~0.2 ev).[2,3] Thus we have a means of investigating the apparent anomaly between the drift tube measurements of Bradbury[2] and of Doehring[3] which yield attachment cross sections of $\sim 10^{-19}$ cm^2 at 0.2 ev and the microwave value[4] of $\sim 10^{-22}$ cm^2 at 0.04 ev. The present measurements are in reasonable agreement with the results of Bradbury and of Doehring, but indicate a decrease in the cross section with decreasing electron energy starting at 0.2 ev in contrast to the Bloch-Bradbury theory[5] which predicts a rise in cross section from 0.2 ev to 0.1 ev followed by a decrease at lower energies.

[1] J. L. Pack and A. V. Phelps, Phys. Rev. **100**, 1229(A) (1955).
[2] N. E. Bradbury, Phys. Rev. **44**, 883 (1933).
[3] A. Doehring, Z. Naturforsch. **7a**, 253 (1952).
[4] M. A. Biondi, Phys. Rev. **84**, 1072(A) (1951).
[5] F. Bloch and N. E. Bradbury, Phys. Rev. **48**, 689 (1935).

C7. Negative Ion Formation and Electric Breakdown for Some Halogenated Gases. W. M. HICKAM AND D. BERG, *Westinghouse Research Laboratories.*—The formation by resonance electron capture of SF_6^- from SF_6 has been shown[1] to occur at less than 0.1 electron volt and to possess an energy width less than 0.05 ev. Utilizing a conventional electron gun and mass spectrometer, the formation of negative ions at low electron energies have been investigated for a number of halogen containing gases used in electric breakdown studies. The SF_6^- peak is used as an energy calibration for establishing the appearance potential and the energy width over which capture occurs for the individual gases. Investigations[2,3] have shown the significance of electron attachment in electric breakdown. It is found that the relative areas of the negative ion curves can be correlated with the electric breakdown voltages. The results suggest that the formation of SF_6^- rather than SF_6^- may be the important process in providing the relatively high electric breakdown value for SF_6. Electron attachment associated with SF_6 and CCl_4 is found to be an extremely sensitive function of the gas temperature. The gases investigated include CCl_4, CCl_3F, CCl_2F_2, $CClF_3$, CF_4, CF_3SF_5, SeF_6, C_2F_3Cl, and $CHCl_2F$.

[1] W. M. Hickam and R. E. Fox, J. Chem. Phys. **25**, 642 (1956).
[2] J. W. Marriott and J. D. Craggs, Electrical Research Association L/T301 (1953).
[3] M. A. Harrison and R. Geballe, Phys. Rev. **91**, 1 (1953).

High-Temperature Plasmas

D1. Pinch Effect in Argon and Helium.* J. W. MATHER, *Los Alamos Scientific Laboratory.*—Experimental evidence will be given showing the self contraction of a high-current gas discharge in a Columbus (linear) geometry. The inward radial velocity is shown to depend on the square root of the applied electric field and inversely on the fourth root of the mass density of the gas. The agreement with theoretical predictions (M-Theory)[1] will be indicated.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] M. Rosenbluth, Los Alamos Scientific Laboratory Report, LA-1850, "Infinite conductivity theory of the pinch" (September, 1954).

D2. Current Distribution in an Impulsive Pinched Discharge.* L. C. BURKHARDT, *Los Alamos Scientific Laboratory.*—A magnetic probe technique has been employed to measure the distribution of current as a function of time in a Columbus (linear) pinched discharge whose current rises to 1.5×10^5 amperes in six microseconds. A positive current sheath forms first near the tube wall and then moves toward the axis with a velocity in agreement with simple theoretical calculations. During this inward motion of the main current, a reversed current flows between it and the tube wall. By the time the main sheath reaches one-third the tube radius, a second positive current sheath forms near the tube wall. Instabilities destroy the pinch after two microseconds, precluding measurements during the rest of the current cycle.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

D3. Instabilities in a Pinched Discharge.* R. H. LOVBERG, *Los Alamos Scientific Laboratory.*—Observations of the instabilities which characteristically destroy the axial symmetry of a pinched discharge have been made using image converter and magnetic probe techniques. It is observed that the predominant instability in a simple discharge in one which pinches off the plasma column at regular intervals ("sausage") and that this instability is removed by the application of a longitudinal magnetic field. The remaining instability is found to distort the discharge column into a helical shape. These results all confirm the theoretical predictions of Kruskal and Tuck.[1]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Los Alamos Scientific Laboratory Report, LA-1716, "Instability of a pinched fluid with a longitudinal magnetic field" (November, 1953).

D4. Neutron Generation From Straight Pinches* (Columbus I'). ROBERT E. DUNAWAY,† *Los Alamos Scientific Laboratory.*—Experiments on the neutrons produced in a high-current pulse discharge in deuterium are described. With 15 kv applied to a straight discharge tube 30 cm in length neutrons are produced at ~1.4 μsec after gas breakdown in a pulse 0.1 μsec in length. The yield, 10^3-10^8 neutrons per discharge, is quite sensitive to gas purity and discharge tube wall material. The axial asymmetry in neutron energy indicates that the neutrons were produced in reactions whose center of mass moves preferentially towards the cathode. Several mechanisms for the production of these neutrons are discussed.

* Work done under the auspices of the United States Atomic Energy Commission.
† Present address, General Atomic Division of General Dynamics Corporation.

D5. Spectroscopic Observations of Pinched Discharges.* EMORY J. STOVALL, JR., *Los Alamos Scientific Laboratory.*—The temperature produced in a pinched discharge in xenon has been determined by the application of the Saha equation of ionization equilibrium to the observed relative intensities of the spectral lines of the consecutive stages of ionization of xenon in the spectrum of the pinch. The degree of compression in density achieved in pinched deuterium has been determined by measuring the broadening of the Balmer series spectrum lines at the time of the pinch. The method is based upon the Holtsmark[1] theory of the stark effect in ionized gases. Similar observations were made in much greater detail on the He II line at 4686 A. In a pinched Helium discharge under conditions of somewhat higher density and temperature. In this case the shape of the line does not agree with that predicted by existing theories of line broadening. The intensity in the wings of the line varies as $(\Delta\lambda)^{-1}$, whereas the Holtsmark theory predicts a variation as $(\Delta\lambda)^{-5/2}$, and the collision theory $(\Delta\lambda)^{-2}$. An attempt to develop a theory consistent with these observations is underway.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. Holtsmark, Ann. Physik **58**, 577 (1919).

D6. Magnetically Driven Electrodeless Shock Tube for the Production of High Energy Plasmas. G. SARGENT JANES, *Avco Research Laboratory.*—High temperatures have been produced in fully ionized hydrogen and deuterium at pressure between 0.08 and 0.8 mm/Hg by means of magnetically driven shock waves. The system is electrodeless. A light gas in a cylindrical shaped 4-in. diameter Pyrex chamber is driven radially inward toward the axis by an axial magnetic field associated with currents in a surrounding single turn coil. A 200 000 ampere current is built up in this coil in 0.5 μsec by means of a capacitive energy storage power supply and a pressurized spark gap. Velocities up to 15 cm/μsec have been measured with the use of photomultipliers and slits. These velocities can be interpreted as leading to temperatures up to 350 000°K by use of the conservation equations. Experimental velocities are in agreement with theoretical predictions assuming that the gas excludes the field by surface currents. It is anticipated that this work can be extended to produce temperatures greater than 1 000 000°K at particle densities of the order of 10^{16}. Under these conditions, the magnetic field terms in the Boltzmann equation will dominate over the collision terms, and anomalous hydrodynamic phenomena may be expected.[1]

[1] Arthur R. Kantrowitz and Harry E. Petschek, in *Magnetohydrodynamics*, edited by Rolf K. M. Landshoff (Stanford University Press, Stanford University, California).

D7. Extremely Large Gas Temperatures in the High Pressure Coaxial Capacitor Discharge. HEINZ FISCHER, *Air Force Cambridge Research Center* (ARDC).—Maximum energy with shortest pulse length is released into the gap of a capacitor discharge when the inductance L of the circuit is reduced to its minimum. As a result of this consideration, special toriodal capacitors were developed which surround the gap coaxially. Maximum gas temperatures in helium (gap 0.2 cm, 35 atmos, breakdown voltage 7 kv, maximum current approximately 63 K amp, current density approximately 1.5×10^6 amp/cm²) exceeding 250 000 degrees Kelvin are calculated from the spectral radiation density, which is measured. The method is described.—Photographs of the spark channel as short as 0.1 μsec after "zero" time (exposure 0.1 μsec) are taken in the gases H_2, He, and A by means of a gated image converter (Mullard 1201) and the growth of the channel as a function of time observed.—The opacity of the channel is measured directly, applying a spherical mirror which images the reflected light back through the channel.

Microwaves; Coulomb Interactions

E1. Study of Radiated Noise from an Arc Discharge. H. A. SCHAFFT AND A. D. KRUMBEIN,* *University of Maryland.*—The radiated noise spectrum of an aluminum arc discharge in air was investigated quantitatively between 100 mc and 650 mc at atmospheric pressure and as a function of pressure. Pulse studies were also made. Radiated noise, which is believed to be caused by relaxation oscillations, could be detected in the entire range from 80 kc to 2200 mc. Quantitative data, however, could not be obtained except in the limited region stated above. Copper and mild steel arc discharges radiated almost no noise in the larger frequency range. In general, the results confirm the work of Skolnik and Puckett[1] for noise obtained with the receiver coupled directly to the arc discharge circuit.

* Now at Nuclear Development Corporation of America.
[1] M. I. Skolnik and H. R. Puckett, Jr., J. Appl. Phys. **26**, 74 (1955).

E2. Microwave Investigation of Disintegrating Plasmas in Mixtures of the Rare Gases. H. J. OSKAM, *Philips Research Laboratories, Eindhoven.*—Measurements concerning the behavior of the afterglow in mixtures of the rare gases are presented. An admixture of atoms with a lower ionization potential than that of the main gas is found to have a great effect on the disappearance of the electrons from the plasma. The afterglow is studied in helium, in the binary gas mixtures, in helium with a small concentration of neon, argon, and krypton, respectively, further in neon, neon-argon, and neon-krypton mixtures. Measurements in these mixtures all show the replacement of the molecular ions of the main gas by atomic ions of the admixture even at very low concentrations of the latter. The process concerned in helium-neon may be a charge-exchange process between a molecular helium ion and a neon atom; in the other mixtures the Penning effect cannot

be excluded. At higher concentrations the atomic ions of the admixture are converted into molecular ions by three-body collisions with an atom of the main gas and an atom of the admixture. The data obtained for the various processes will be presented.

E3. Microwave Diagnostics for Controlled Fusion Research.* CHARLES B. WHARTON, *University of California, Livermore.*—High temperature plasma research, aimed mainly toward controlled thermonuclear reactions, has been greatly facilitated by the development of a number of microwave measuring techniques, called "microwave diagnostics." These schemes are based in part on previous plasma microwave studies, but mostly on ideas generated at UCRL over the past five years in conjunction with the AEC Project Sherwood. The properties of a plasma of arbitrary geometry measurable by these techniques are: average spatial density, density distribution, collision frequency, electron "kinetic temperature," recombination, and other loss rates, all as a function of time, with or without strong magnetic fields present. The quantities measured directly are the phase and absorption coefficients of the dispersive propagation "constant," the electron and ion gyrofrequencies, intensities of electromagnetic radiations emanating from the plasma, and emission spectra of these radiations. A brief theoretical discussion of the mechanisms involved and experimental results indicating satisfactory correlation are presented. Experimental setups and millimeter wavelength equipment employed in the experiments are described.

* Work performed under auspices of the U. S. Atomic Energy Commission.

E4. Oscillations in a Plasma in a Magnetic Field. H. W. BANDEL AND R. M. HILL, *Sylvania Electric Products, Inc., Mountain View.**—A study has been made of oscillations which occur within a gas filled smooth anode magnetron. As has been previously observed by Nelson,[1] the modes of oscillation indicate that there are two conditions on the frequency which must be satisfied simultaneously; the frequency must be approximately equal to an integral multiple of the electron cyclotron frequency and it also depends on the electron density. Rough relative density measurements give evidence that the oscillations follow the dispersion law $\omega^2=\omega_c^2+\omega_p^2$. Here ω_p is the Langmuir-Tonks plasma angular frequency and ω and ω_c are the oscillation and cyclotron angular frequencies, respectively. Using probes inside the anode, simultaneous measurements of relative phase and amplitude of signals as a function of azimuthal angle have shown that there is no azimuthal variation. This result rules out Nelson's theory which postulated the existence of azimuthal oscillations. Hard tube magnetron oscillations at angular frequencies of approximately $\omega_c/\sqrt{2}$ also have been found to have no azimuthal variation.

* This work performed under Signal Corps Contract.
[1] D. Nelson, Final Report Contract No. W19-122-ac-34 (1954).

E5. Microwave Propagation in a Hot Magneto-Plasma. J. E. DRUMMOND, *Stanford Research Institute.*—A theoretical study of the propagation of transversely polarized microwaves through a very hot, dense plasma in a magnetic field is presented. This study is based upon a more general conductivity tensor presented at an earlier conference (to be published). It is shown that for certain ranges of the parameters the index of refraction, (n), differs widely from that predicted from the usual theory; regions of nonpropagation (i.e., for which n is imaginary) now become propagating regions, and the index of refraction depends upon electron density and densitometer *seem* feasible. The temperature range considered is such that $10^{-3}<\langle v_1^2\rangle/c^2<10^{-2}$ where $\langle v_1^2\rangle$ is the mean square electron speed normal to the magnetic field and c is the speed of light. The density range considered is such that $40<\omega_p^2/\omega^2<400$ where ω_p is the electron plasma frequency and ω the microwave frequency.

E6. Effects of Electron-Electron Interactions on Cyclotron Resonances in Gaseous Plasmas.* RUDOLPH C. HWA, *University of Illinois.*—The long-range part of the Coulomb interactions has been found to have a negligible effect on the velocity distribution function of the electrons for densities less than 10^{12} cm^{-3}. To account for the short-range forces the Boltzmann-Fokker-Planck equation was set up in cylindrical coordinates, and was solved numerically on the digital computer for various values of magnetic field and charge densities. The results indicate that the electron-electron scattering reduces the absorption at the peak of the cyclotron resonance and broadens its width. With the magnetic field equal to zero it is found that the electron-electron interaction alters the ac conductivity of the plasma by no more than a few percent.

* Supported by the Air Force Cambridge Research Center.

E7. Electron-Electron Interaction and Heat Conduction in Gaseous Plasmas.* T. SEKIGUICHI† AND L. GOLDSTEIN, *University of Illinois.*—The phenomenon of heat conduction in gaseous plasma is observed in order to explore the problem of the mutual electron interaction. In addition to the technique of interaction of pulsed microwave in decaying plasmas, the phenomenon of "afterglow quenching" is exploited in the experiments. The experimental values of the thermal conductivity, in low gas pressure neon and xenon plasmas of adequately high charge density, are determined by two different methods. They have been found to be of the order of $10^{-6}\sim10^{-5}$ (joules/cm sec degree) for the electron density range $10^{11}\sim10^{12}$ (1/cm^3) at room temperature ($\sim$300°K). The most significant result of these experiments is that the thermal conductivity in the plasmas described is chiefly determined by heat flow in the electron gas of the plasma. Thus the mutual interaction of the electrons plays a predominant role in the phenomenon of heat conduction. The experimentally obtained values of the thermal conductivity are in agreement within less than one order of magnitude with those given by the theory of Spitzer and Härm.

* Supported by Air Force Cambridge Research Center.
† Visiting from University of Tokyo, Japan.

E8. Theory of Run-Away Electrons.* H. DREICER, *Los Alamos Scientific Laboratory.*—This paper applies the Boltzmann method to the problem of electrons moving through a gas of positive ions under the influence of a static uniform electric field, E, of arbitrary strength. In sufficiently large fields the zero order electron velocity distribution is chosen to be Maxwellian, displaced by the electron drift velocity. This assumption is based upon the fact that the rate of energy partition due to electron-electron encounter is larger than the rate at which electron-ion encounter converts drift energy into random energy. The Boltzmann equation shows that at constant temperature, electrons are accelerated indefinitely for E larger than a critical field, i.e., runaway. If Joule heating occurs, stationary solutions do not exist, even when the critical field exceeds E. For sufficiently small fields the problem changes its nature. Only high energy electrons in the "tail" of the distribution run away, the time scale for appreciable depletion of the "body" being determined by a diffusion process in velocity space from the body into the tail. The Boltzmann formulation yields the probability for depletion as a function of time. Time scales for this type of runaway are large compared to mean free collision times.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

Breakdown

F1. Low Pressure Microwave Plasma in a Magnetic Field.* D. O. AKHURST, S. J. BUCHSBAUM, E. I. GORDON, *M.I.T.*—A low pressure hydrogen plasma in a magnetic field is described. The plasma is contained in a narrow cylindrical quartz tube along the axis of a cylindrical microwave cavity that oscillates in the TE_{111} mode at a resonant wavelength of 10 cm. The configuration and strength of the magnetic field is such that electrons can gain energy from the microwave field through the cyclotron resonance effect. At high pressures both the breakdown and maintaining fields exhibit the well-known cyclotron resonance effect. However, at low pressures when the electron mean free path (in the absence of a magnetic field) is larger than the length of the quartz tube, it is easier to produce and maintain the plasma with a magnetic field a few percent off the value of magnetic field required for cyclotron resonance. Phenomena responsible for this "displaced" resonance will be described.

* This work was supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research); and in part by the U. S. Atomic Energy Commission.

F2. Electron Diffusion Within a Cylindrical Microwave Cavity. R. J. MUNICK, *Hughes Research Laboratories.*—The equation for the diffusion of free electrons in a gas subjected to a microwave electric field within a cylindrical cavity under the influence of a continuous source of ionization has been solved for the concentration of electrons as a function of position and time, subject to the boundary condition that the concentration at the walls is proportional to its gradient. It was assumed that the ionization and diffusion coefficients are constant and that recombination of electrons with ions is negligible. The continuous-wave breakdown criterion agrees with that of Herlin and Brown,[1] but the diffusion length is altered by the boundary conditions. The continuous source of ionization does not affect the breakdown threshold. A paradoxical result is that the application of a microwave field of less than threshold strength can reduce the equilibrium concentration of electrons already present.

[1] M. A. Herlin and S. C. Brown, Phys. Rev. **74**, 910 (1948).

F3. Multipacting Modes of High Frequency Breakdown. ALBERT J. HATCH, *Argonne National Laboratory*, AND H. BARTEL WILLIAMS, *New Mexico College of A. and M.A.*—A previously developed average electron theory for the 1/2-cycle multipacting mode of low-pressure high-frequency breakdown (secondary electron resonance) has been extended to higher order modes. A semitheoretical plot of breakdown voltage V *vs* the product of frequency times electrode separation fd using representative fitting parameters is given for the 1/2- through 9/2-cycle modes. In addition to the customary 1/2-cycle cutoff the theory predicts a modified cutoff in each of the mode transition regions. Breakdown data for machined alclad electrodes at 2 microns show 1/2-cycle cutoff at about 100 mc-cm/sec and 3/2-cycle cutoff at about 450 mc-cm/sec. The 3/2-cycle cutoff is indicated by a dip in the breakdown curve and is strongly dependent on electrode surface conditions. The concept of higher order multipacting modes clarifies the breakdown mechanism in the transition region between multipacting and diffusion controlled breakdown. An examination of typical microwave diffusion breakdown data shows that at pressures sufficiently below the mean free path limit the observed breakdown voltages are consistent with those observed for various multipacting modes.

* The major portion of the work described here was performed at New Mexico College of A. and M.A., supported by the Bureau of Ordnance, U. S. Navy.

F4. Three-Dimensional Potential Well Produced by the Secondary Electron Resonance Mechanism. H. BARTEL WILLIAMS, *New Mexico College of A. and M.A.*—When the secondary electron resonance mechanism (multipacting) operates at low pressures, 0.1 micron Hg or less, a region in space is created in which the averaged charge density is negative. A positive ion sees this region as a three-dimensional potential well. Computations based on computed electron trajectories and experimentally measured parameters have been made. Curves of force and potential functions derived from these computations will be presented. A discussion of the magnitude, shape, and stability of this potential well will be presented. Some uses of the potential well will also be discussed.

F5. High-Frequency Breakdown in Air and Hydrogen. ELSA HUBER SOLT AND PHILIP M. PLATZMANN, *Hughes Research Laboratories.*—Breakdown electric fields between parallel-plate electrodes have been measured for air and hydrogen at a frequency of 10 mc, with plate separations varying from 0.5 to 4.0 cm. The measurements have been carried out to considerably higher values of pd than have previously been reported for high frequencies, *viz.*, to 150 and 400 mm Hg×cm in air and hydrogen, respectively. For electrode separations greater than the electron oscillation amplitude, results are in general agreement with measurements of other workers at the lower pd values, both at microwave frequencies and 200 mc. However, the independence of breakdown field on gap length reported by Prowse and Lane[1] at 11.5 mc was not observed. In the present work, E/p was still decreasing slightly in both gases at the highest pd, indicating that diffusion still contributes to removal of electrons from the gap.

[1] W. A. Prowse and P. E. Lane, Appl. Sci. Research **B5**, 127 (1955).

F6. Current and Time Studies of the Positive Point Corona in Hydrogen.* L. A. BORNSTEIN AND L. H. FISHER, *New York University.*—The previous positive point-to-plane corona studies in air, nitrogen, and argon[1,2] have been extended to hydrogen, with strikingly different results. Observations have been made of steady-state current-voltage characteristics at pressures near atmospheric, and at voltages below onset of a self-sustained discharge. These measurements provide strong evidence that a secondary mechanism must be invoked to account for the observed currents. Using Rose's[3] measurements of α, values of γ were computed to be of the order of 10^{-4}, in good argeement with those found in uniform field studies in H_2.[4] Time lag measurements of the pulsed glow corona in H_2 yield formative lags less than 0.1 μsec even very close to threshold. This rules out the cathode as an agent in the discharge buildup of the pulsed glow corona in H_2. A gas-dependent mechanism is proposed to account for the short formative times. An unusual quenching of the discharge current by ultraviolet irradiation has been observed.

* Supported by the Office of Naval Research.
[1] M. Menes and L. H. Fisher, Phys. Rev. **94**, 1 (1954).
[2] L. A. Bornstein and L. H. Fisher, Phys. Rev. **100**, 1228 (1955).
[3] D. J. Rose, Phys. Rev. **104**, 273 (1956).
[4] D. J. DeBitetto and L. H. Fisher, Phys. Rev. **104**, 1213 (1956).

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Minutes of the Fall Meeting of the Ohio Section of the American Physical Society Held at the Cincinnati Milling Machine Company, Cincinnati, Ohio November 1–2, 1957

THE regular fall meeting of the Ohio Section of the American Physical Society was held at the plant of the Cincinnati Milling Machine Company, Cincinnati, Ohio, on Friday and Saturday, November 1–2, 1957.

Friday afternoon was given to an excellent tour of the Research Laboratories and the plant of the Cincinnati Milling Machine Company. After the tour the research men of the Cincinnati Milling Machine Company presented the following papers: "Electrode Discharge Machining" by Dr. Phil Berghausen; "Hydraulic Servo-Control Simulation" by Mr. Richard R. Weber; and "Energetics of Plastic Deformation of Metals" by Dr. Robin O. Williams. Arrangements for this much appreciated visit were made through Dr. M. E. Merchant, Mr. Robert Marshall, and Mr. Robert R. Weber of the Company. There was no evening session.

Saturday morning was spent again in the Auditorium of the Cincinnati Milling Machine Company where the four contributed papers were heard. Three represent new work and have abstracts which follow; the fourth, "About Satellites and Moon Watch," by Mr. Kenneth E. Kissell, of Dayton, Ohio, was of general nature and there is no abstract.

Leon E. Smith, *Secretary*
Ohio Section of the American Physical Society
Dennison University,
Granville, Ohio

Invited Papers

1. **Electrode Discharge Machining.** Phil Bergenhausen, *Cincinnati Milling Machine Company.*
2. **Hydraulic Servo-Control Simulation.** Richard R. Weber, *Cincinnati Milling Machine Company.*
3. **Energetics of Plastic Deformation of Metals.** Robin O. Williams, *Cincinnati Milling Machine Company.*

Contributed Papers

1. Subtractive Color Demonstrations in the Teaching of Color. Isav Balinkin and C. Harrison Dwight, *University of Cincinnati.*—In the usual experiments upon color given in the physical optics laboratory, the spectral transmission of the samples of dyed materials is plotted as a function of wavelength by the proper settings of a spectrophotometer, while the color of the filter is seen by the eye. In another experiment the transmittance curves of *two* such materials *in series* are observed simultaneously with the visual impression of the residual color of the combination. Such superimposed transmittance curves would give a quantitative result for the subtractive color mixture provided by the two filters. The multiplication of the one curve by the other would result in the transmittance curve of the group. It occurred to the authors that if it were possible to see through two given filters at the same time and, by merely glancing upward, to observe the conbination of the two transmittance curves of these filters, the student of colorimetry would have a graphic and simple means of studying the important phenomena of subtractive color mixture. Described herewith is a device which may be termed a SUBTRACTIVE COLOR SLIDE RULE which permits the superposition of any of four properly chosen "blue" filters upon any of four properly chosen "yellow" filters, while observing the superposition of their corresponding transmittance curves. The device in its present form permits sixteen color combinations and may be revised mechanically so that combinations of any two filters, and their curves, may be projected upon a screen for viewing by a large class.

2. Energy Distribution of Electrons Emitted by Collisions of K Ions on Neon, Argon, and Krypton.* D. E. Moe and O. Petsch, *Western Reserve University.*—Previous experimental work done on ionization of rare gases by positive ions led one to suspect the existence of fine structure in the energy spectrum of the emitted electrons. In the present research on ion-atom collisions between K^+ ions and Ne, A, and Kr this fine structure in the energy spectrum of the emitted electrons definitely was observed. Electron energies were measured with a 180° magnetic spectrometer. For each gas studied the electron energies measured were independent of the incident K^+ ion energies over a range extending to 900 ev of ion energy. This would indicate that some intermediate mechanism becomes important during the collision process.

* This project was supported by a grant from the National Science Foundation.

3. The Ohio State University Cyclotron Scattering System.* H. A. Lackner, H. F. Bowsher, G. F. Dell, and H. J. Hausman, *The Ohio State University.*—A system has been designed and constructed to focus and momentum analyze the external charged particles accelerated in the cyclotron. The external cyclotron beam is extracted electrostatically from the cyclotron vacuum tank into a 2-in. o.d. brass beam tube. The beam is focused by a pair of quadrupole focusing magnets, bent through an angle of 15 degrees by a conventional sector type magnet and focused at the center of a 12-in. o.d. scattering chamber. Detection of the charged particles emitted from bombarded targets placed at the center of the scattering chamber is accomplished by means of a scintillation counter mounted vertically through the top lid of the scattering chamber. The particle detector can be rotated about the target position for angular distribution analysis. A high-resolution, double-focusing magnet spectrometer for the momentum analysis of charged particles emitted in nuclear reactions is under construction. Experiments not in progress will be described.

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4. About Satellites and Moon Watch. Kenneth E. Kissell, *Dayton, Ohio.*

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